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Design of a low-cost Photon Height Analyzer for a Mössbauer spectrometer

Luis Fernando Sarmiento Báscones

SUPERVISED BY

Pere Bruna Escuer

Óscar Casas Piedrafita

Universitat Politècnica de Catalunya
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BY

Luis Fernando Sarmiento Báscones

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Universitat Politècnica de Catalunya

SUPERVISED BY:

Pere Bruna Escuer
Departament de Física Aplicada
(EETAC – UPC)

Óscar Casas Piedrafita
Departament Enginyeria Electrònica
(EETAC – UPC)

ABSTRACT

Mössbauer spectroscopy is a technique that allows investigating with high accuracy the changes in the energy levels of an atomic nucleus due to the surrounding environment. The technique consists in measuring the energy dependence of the resonant absorption of Mössbauer gamma rays by nuclei. To obtain these gamma rays a radioactive source is needed. In the laboratory, the isotope ^{57}Co is used, which spontaneously captures an electron to reach a metastable state of ^{57}Fe, which in turns decays in a more stable state (ground state) by a gamma ray cascade that includes the 14.4 keV Mössbauer gamma ray. To work just in this energy range, the spectrometer has an energy window, which should be centered at 14.4 keV. The objective of the present work is to design and build a low-cost analyzer of the photon energy emitted by the radioactive source, in order to be able to check easier and automatically where the energy window is located and, if necessary, to know how its position should be modified.

The steps necessary to perform this work are the following. a) Characterization of the main properties of the emission's peaks (time duration and amplitude) that are going to be analyzed. These features are needed to know the characteristics of the data acquisition system (i.e. sampling rate, bit number and price). b) Signal analysis in order to differentiate properly all the emission peaks from peaks due to noise or overlap. c) Creation of software to automate all the steps to do and prepare a graphical user interface easy to understand.

Finally, the performance of the designed system will be evaluated and compared with analogous commercial equipment.

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INTRODUCTION

The present work consist in designing and building a low-cost analyzer of the photon energy emitted by a radioactive source, in order to be able to check easy and automatically where the energy window for selecting the photons needed in a Mössbauer experiment is located. Moreover, if necessary, it will allow to know how its position should be modified and also to obtain information about the dead time of the detector.

It is important to keep in mind that the equivalent commercial equipment and software cost around 4000 € fifteen years ago. The total price of our system is 200 € (the price of the USB digital oscilloscope), therefore it is necessary to understand that it is highly complicated to obtain the same features on accuracy or time duration.

On the one hand, in order to determine where the energy window is located and also for getting information about the dead time, it is not necessary for the system to be extremely accurate. Accepting a small error over precision we will save an important quantity of budget (using a system with less bit's number, *n*).

On the other hand, the Photon Height Analyzer is going to be used when the set up is changed (because the radioactive source is changed, or the distance between detector to sample, or sample to source is changed) twice or three times a year, consequently the large time duration of data acquisition can be accepted because this also will decrease the final price of the project (using a system with a slower analogue to digital converter).

Outline

The idea of this chapter is to yield an overview of the project, indicating the purpose of the project and their motivation. It also will provide to the reader the organization of the project and the methods used.

Chapter 1 contains a basic overview about the Mössbauer Spectroscopy in order to fix the physics context of the project.

In Chapter 2 is explained how it is the measuring system and it is also included a study about the architecture of the system and errors. It will permit us to fix the features needed for our acquisition data system DAS and decide that the best option to wire our system is using an external divisor probe (EDP).

Before the data treatment it is necessary, first of all, to understand the possible errors in the measure. In addition, it allows to obtain a deep knowledge about how works every instrument of the set up.

Chapter 3 is dedicated mainly to proportionate the features of our chosen DAS as sampling frequency or data transfer velocity; it also contains an explanation in depth of the MatLab code created for the first data treatment, where it is confirmed that the data obtained and the DAS proportionate greats results. The idea to use MatLab has a clear explanation, considering the interest of the author of the project in increase their knowledge about LabView (LV) programming, was decided to use MatLab because LV contains a function called *MatLab script*, which allows to pass directly the MatLab code to LV. In Chapter 4 it has been also determined some other parameters necessaries for the right work of the code such us the minimum value accepted for a maximum peak detected (50 *mV*) or the threshold values to measure dead time ($V \in [0\,, 35\ mV]$ to avoid dead time).

In Chapter 4 it is shown step by step the final LV block diagram, explaining all the highlights; it is also presented a kind of user's manual in order to proportionate to the laboratory worker all the information needed to do a good energy window calibration.

Finally, Chapter 5 includes the main conclusion obtained during the project and also some ideas about what could be the future work in order to improve the project.

Chapter 1

PRINCIPLES OF MÖSSBAUER SPECTROSCOPY

Rudolf Ludwig Mössbauer discovered at the end of the 50's the recoilless resonant absorption of gamma rays **[1]**, also known as Mössbauer effect (ME). It consists in the recoilless emission of gamma rays by a radioactive nucleus followed by the absorption of these rays by other nucleus of the same species (see Figure 1.1).

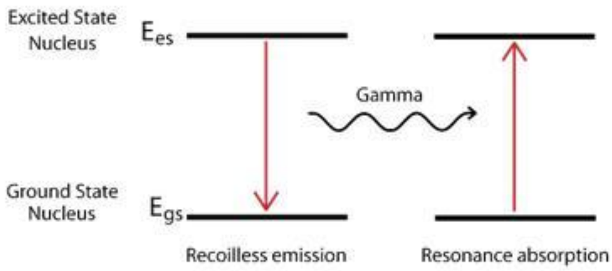

Figure 1.1 Basic scheme of Mössbauer effect

Although the theoretical principle of ME was already known many years before, no one was capable to recreate it in the laboratory. Mössbauer realized that it was necessary to have the radioactive sample in a solid matrix to be able to have the emission process without recoil. As the nuclear energy levels have a very narrow width, the energy loss due to recoil of the emitting nucleus was enough to avoid the resonant absorption. Therefore, the insertion of the radioactive nucleus in a matrix was the only way to obtain the effect. The spectroscopic technique based on this effect is called Mössbauer Spectroscopy (MS).

The energy levels of a nucleus in a solid are modified by its environment. MS it is hugely sensitive to energy changes ($\sim 10^{-8}$eV), hence it enables to study three main interactions between the absorbent nucleus and the surrounding nucleus and electrons (hyperfine interactions): i) the electric monopole interaction between the nucleus and its electrons that produces a shift in the nuclear energy levels called isomer shift (IS), ii) the electric quadrupole interaction between the nuclear quadrupole moment and an inhomogeneous electric field that produces a splitting of an energy level called quadrupole splitting (QS), and iii) the magnetic dipole interaction (DI) between nuclear magnetic dipole moment and a magnetic field that produces a further splitting of the energy levels (see Figure 1.2).

The information obtained from these interactions is useful not only in physics and chemistry, but also in a wide range of disciplines as biology, geology or archaeology; for instance: study mineralogy of rock, soil and dust at Gusev crater in Mars **[2]**, measurement of the relaxation time of ultrasonic vibrations in Fe foils **[3]**, study of the

basilar membrane motion in the pigeon **[4]**, measure of the astrophysical parameter red shift in Earth **[5]**.

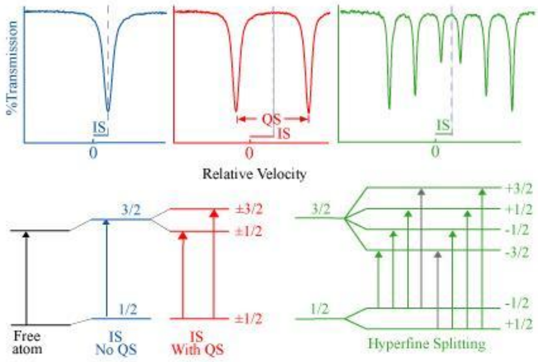

Figure 1.2 Characteristics of Mossbauer spectra related to nuclear energy levels. Hyperfine Splitting includes IS, QS and DI [6]

In this chapter we will present the most relevant aspects of the MS experimental setup used in the laboratory.

1.1. Mössbauer Spectroscopy experimental configuration

This is the scheme of a typical Mössbauer spectrometer:

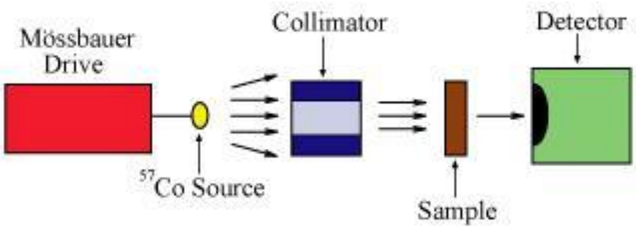

Figure 1.3 Basic scheme of MS instrumentation

It is worth to explain in depth the three main elements: radioactive source, detector and the amplifier at which the detector is connected.

1.1.1. Radioactive source

It is possible to work with a lot of different isotopes in MS, but the most used and the one that it is used in the laboratory of this master thesis is radioactive ^{57}Co (because ^{57}Fe has the most advantageous combination of properties for MS **[7]**). The radioactive cobalt isotope undergoes a transition by spontaneous electron capture to reach a metastable state of ^{57}Fe, which in turns decays in a more stable state

(ground state) by a gamma ray cascade that includes the 14.4 keV gamma rays that are used in MS (see Figure 1.4). It is necessary to place the radioactive source in an electromechanical transducer driven by an appropriate electronic system to obtain by Doppler's effect **[8]**, a slightly wider range of energy to analyze the absorber. Without this energy range one could only study pure Fe. It is important to remember that the studied system determines the radioactive source needed. For example, with the ^{57}Co source only systems containing Fe can be studied.

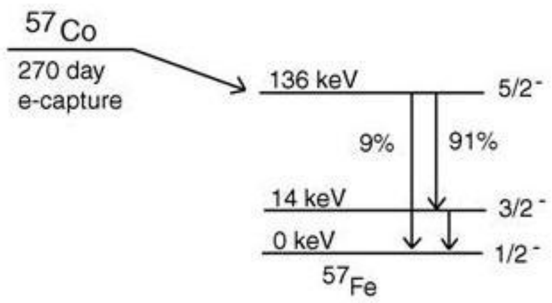

Figure 1.4 ^{57}Co Decay Scheme

It is essential to keep in mind that the objective of the project is to design a system able to measure the energy spectra of the gamma ray cascade in order to be able to select only the photons with 14.4 keV necessary for the ME.

1.1.2. Detector

There are three different kinds of detectors to work with low energy gamma ray: a) gas proportional counter (energies lower than 40 keV), b) scintillator (energies between 50-100 keV, c) Solid state detectors. Due to the energy of Mössbauer gamma rays (14.4 keV) the most efficient detector is a gas proportional counter.

A gas proportional counter consists in a metallic recipient connected to the ground and an inner metallic wire, between which a high voltage difference (around 2 kV) is stablished. The detector has a Beryllium window transparent to the photons that ionize an inert gas (in the detector of our laboratory is a mixture of Xe and CO_2) causing an electron avalanche.

It is possible to observe in figure 1.5 the spectrum of all the received photons and it is easy to realize that not all the photons with a very well known energy level are located in a single value; they are spread around it. That happens because not all the photons travel the same distance as they enter into detector with different input angles.

The high energy photons produced in the ^{57}Fe decay (122 and 136 keV) are not enough amplified in the detector because of the gain of the proportional detectors at these energies is too small (As was argued before, it works successfully in events involving maximum energies of 40 keV); nevertheless some of these gamma rays provokes Compton's effect **[9]** that produces emission in the zone of tens keV. In consequence this zone is more pronounced for smaller energies.

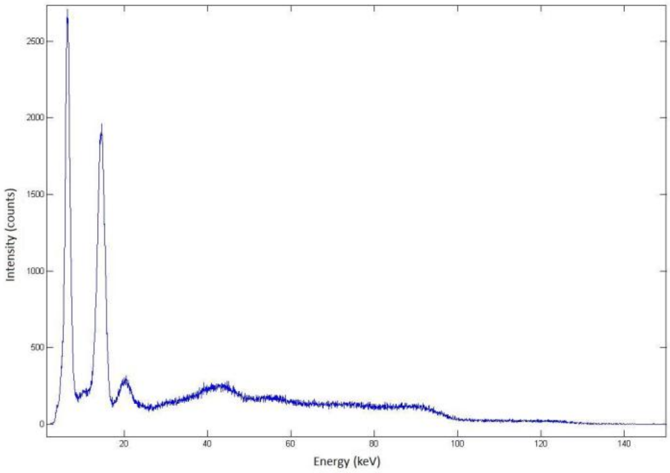

Figure 1.5 Spectrum obtained with a commercial photon height analyzer

The output data of the detector offers the possibility to study two different characteristics depending on the electronics used after it; it is possible to study the amplitude and shape of the gamma rays emitted in order to get information about the properties of the source and configuration of the experiment, this is also called Photon analyzer; it is also possible to study the different hyperfine interaction in the absorber with a MCA (Multi Channel Analyzer), also called spectrum analyzer.

As was discussed in the introduction, we are going to analyze the energy of the photon emitted by the radioactive source (photon analyzer).

1.1.3. Pre-Amplifier and Amplifier

The pre-amplifier normally consists in a charge integrator. The charge collected in a capacitor is proportional to the photon energy. A resistance situated in parallel with the capacitor produce an exponential discharge; the time that takes the capacitor to discharge is a key parameter because, if during that time other photon arrive, then its energy amplitude will we modified as shown in figure 1.6.

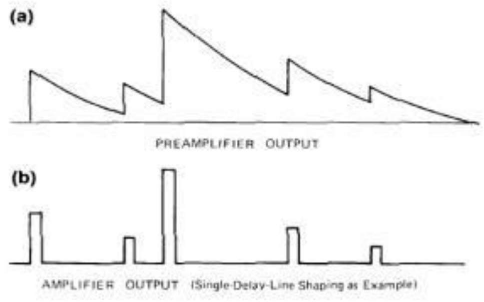

Figure 1.6 Scheme of preamplifier and amplifier output

The way to avoid that effect is either decreasing the arrival's rate (not useful due to the increment of measure time) or changing the shape of the pulse, which is done by the amplifier (see Figure 1.7).

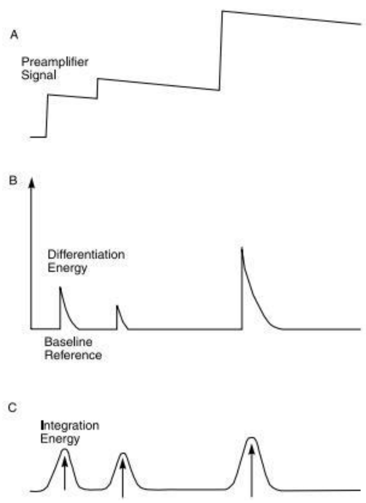

Figure 1.7 Typical Amplifier Pulses [10]

The amplifier is a critical component on the detection stage as a consequence of its characteristics: gain range, output pulse shape and the relation between signal and noise that determine the output data. The amplification in the area of interest is lineal, maintaining the relation between energy and amplitude of the peak.

The amplifier used in the laboratory is the Canberra's model 2022 which uses a Near-Gaussian shape working as unipolar output time to peak 2.35x shaping time, and pulse width 7.3x shaping time (data extracted from Operator's manual). It means that if another pulse arrives before 9.65x shaping time the amplifier will suffer stacking; In this case the energy window will accept events that has not the 14.4 keV needed and will discard events with the proper Mössbauer gamma ray energy.

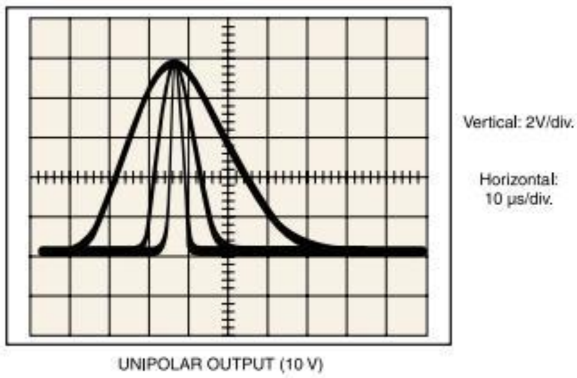

Figure 1.8 Unipolar output with three different shaping time: 12, 4 and 1 μs [11] from wider to thinner

As a comment, the data of the duration of the event shows that the peak's shape is not symmetric (check in Figure 1.8).

Chapter 2

MEASURING SYSTEM. ARCHITECTURE AND ERRORS

All the elements in a circuit, either active or passive, could modify (introduce errors) in amplitude or frequency the output data that is going to be measured. This is the reason why, before analyzing in depth the data to obtain the photon's energy spectrum, it is always advisable to study the architecture of the instrumentation system to receive the signal, in order to be sure that the data have as less error as possible.

This chapter contains four well differentiate parts.

Section 2.1, will be dedicated to analyze the architecture of the measuring system necessary to obtain the signal in order to determine which elements make up the system analyzed.

In section 2.2 the actual system used in the laboratory will be compared with the different devices that allow acquiring the amplifier's signal. This section also contains the study of the amplifier's signal because it should ensure that the data acquisition system (*DAS*) that is going to be bought complies all the requirements of the project.

It is essential to determine device's features as the sampling frequency f_s necessary to obtain a good digital reconstruction of the signal, the number of bits (n) to obtain accurate data, and finally the bandwidth, without forgetting that one of the goals of the project is to design a low-cost equipment.

Section 2.3 will compare the errors caused by the actual type of wiring with the effects obtained with an external divisor probe.

Finally Section 2.4 will analyze the whole system

2.1. Architecture of the instrumentation system

The system used in the laboratory consists in three basics elements (Figure 2.1): i) amplifier; ii) wire type; iii) Data Acquisition System (*DAS*).

The amplifier send the signal through its output impedance composed of a resistance (100 Ω) and an output inductance with a non-specified value in the manual.

The actual wire connexion is a 1 meter length coaxial cable that introduces an impedance in form of capacitance (80 pF each meter length).

And the acquisition system device that has an input impedance formed by a resistance in parallel with a capacitance.

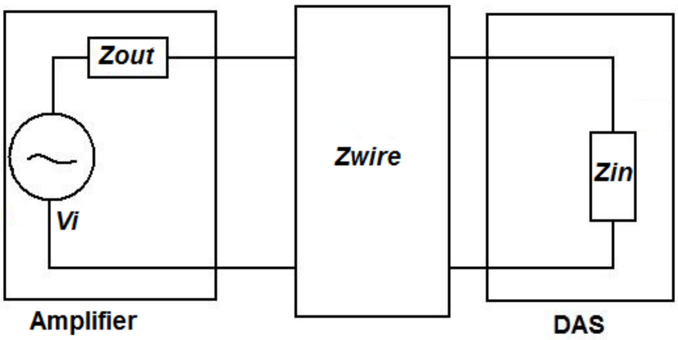

Figure 2.1 Scheme of the system.

Once the data acquisition system has been decided, then the unique possible modification in the scheme is to change the type of wire between the amplifier and the *DAS*.

2.2. Data Acquisition System

The actual data acquisition system used in the laboratory is called MCDLAP; it is an ADC (Analogue to digital signal converter) with a multichannel data processor. The card not only provides the user with a high resolution Pulse Height Analyzing ADC but also with a complete Multichannel data processor. The ADC is a 16 kchannel with 14 bits resolution and 100 MHz clock rate. The card is particularly designed for use in x-ray spectroscopy. Its price is 4000€.

The features of this system are so powerful that it is necessary to keep in mind that we will work in a low-cost project. In consequence it will be impossible to compete with the previous system in terms of time of execution or precision. The idea is to buy a low-cost acquisition system with its features good enough in order to obtain a good Photon Height Analyzer, not to design a system as powerful as the actual.

The objective of this project is to replace this system by another one cheaper. Then, the purpose of the project is not only to buy a low-cost acquisition system but also to design software that allows to obtain a good photon energy spectrum and also to be able to obtain information of the dead time.

The first step was to convert an analogue signal into a digital one. Therefore, the acquisition of the data could be done (if it is not considering the actual device) mainly with one of these two options: a *DAQ* (Data AcQuisition) device or a *USB* (Universal Serial Bus) digital oscilloscope.

The relation between cost and performance was clearly favourable for the *USB* digital oscilloscope. That is because the *DAQ* usually has between 8, 16, or 32 channels and they need a huge sampling frequency to obtain the possibility to work in parallel with all of them, it implies also a huge transfer data velocity that makes the device more powerful but also increase the price.
To decide which oscilloscope would be the best option it is important to determine its main specifications: f_s, *n* and Bandwidth. Then the first thing to do is to observe the signal and characterize it with a commercial analogue oscilloscope.

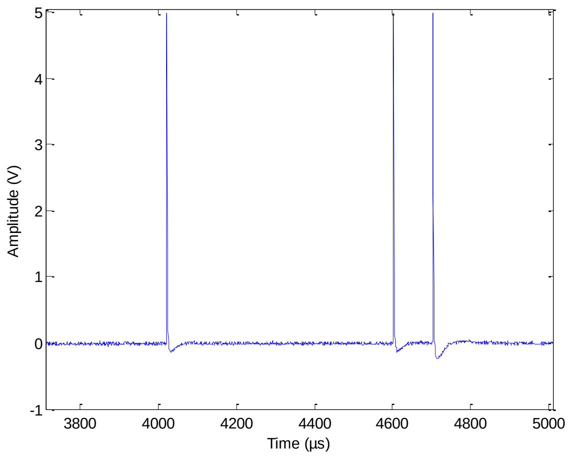

Figure 2.2 Example of the (digital) signal.

With a signal example (see figure 2.2) it is possible to determine the features that will decide the optimum device.

2.2.1. Analysis of the number of bits

The first parameter to analyze was the required amplitude's signal range. This parameter determines the maximum value of peak to peak voltage (v_{pp}) admitted. The output signal had a maximum value of 5 V and a minimum of -2 V, thus the minimum (v_{pp}) accepted would be 10 V, in order to avoid the clipping effect that could saturate the oscilloscope.

Once the value of v_{pp} is known, it is possible to know the needed *n* (number of bits) fixing previously the required data resolution using:

$$V_{resolution} = \frac{V_{max} - V_{min}}{2^n} = \frac{V_{pp}}{2^n} \quad \textbf{(2.1)}$$

It is known that the electronic devices use an even number of bits; therefore, the discussion was focused between 8, 10 or 12 bits. In Table 1 the resolution obtained is shown as a function of the bit's number for v_{pp} equal to 10 V.

Table 2.1 Resolution offered depending on the number of bits.

n	$v_{resolution}(mV)$
8	39,1
10	9,8
12	2,4

It is clear that this parameter will affect directly the final photon's energy spectrum and the final cost. As an example, a 12 bits oscilloscope is almost five times more expensive than the equivalent 10 bits oscilloscope (See annex I).

2.2.2. Analysis of sampling rate

The sampling rate is the other key parameter, because it will determine how the shape of the signal will be rebuilded. A higher sampling rate implies a better reconstruction of the peak's shape (Figure 2.3) and in consequence the photon's energy spectrum will be more accurate.

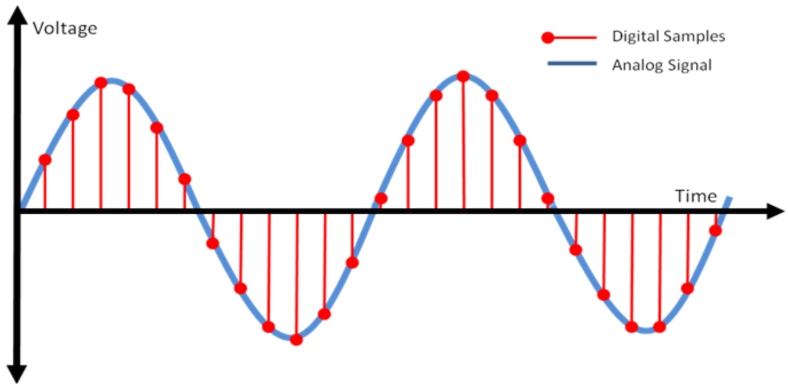

Figure 2.3 A/D (Analogue/Digital) Converter, the sampling rate could be seen as how many points it are going to be used to represent the signal

It is obvious that the best sampling rate would be ideal, but the cost of the device increases quickly when increasing the sampling rate.

To be able to decide which sampling rate should be good for the project, it is necessary to know how the shape of the signal to analyze is and also which is the less intense peak detected. The complete peak could be properly represented as a kind of delta positive (as maximum will have 3 points) peak and then a near-Gaussian peak (explained in Chapter 1) and we should decide how many points are needed to represent it.

The peak chosen (see Figure 2.4) in the signal to work with had a voltage amplitude of 2.75 V approximately, and a duration of 70 μs. With this data, the minimum

sampling rate accepted should be 0.5 Msample/sec in order to have 35 points to represent the curve.

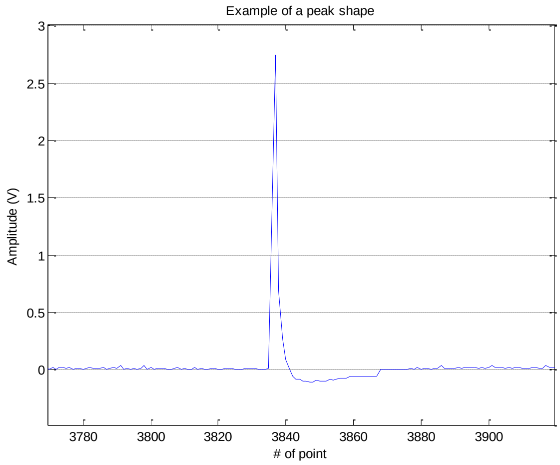

Figure 2.4 Shows one of the peaks detected with the USB oscilloscope.

It is clear that the f_s could be improved, but in consequence the transfer data velocity would be increased; it implies that the cost would increase considerably.

2.2.3. Oscilloscope requirements summary

With the study done above (section 2.2.1 and 2.2.2) it is possible to conclude that the future oscilloscope should has at least 0.5 Msample/sec as a sampling frequency, and ten bit's number. If it is possible to find an instrument that improves these requirements and also keeps the cost then it is going to be possible to obtain more accurate data.

The final decision was to buy a low-cost *USB* Oscilloscope called PropScope; it has a sampling rate up to 25 Msample/s, bit's number of 10, 20 MHz of bandwidth, 35 Kb/s of data velocity transfer; and also includes a function generator and two external divisor probes.

The complete list of oscilloscopes considered is detailed in annex I.

2.3. Errors introduced by effects of non-ideal system

Ideally the circuit could be seen as an amplifier that is connected to the oscilloscope, which is the element responsible to acquire the signal. But as was explained in section 1.1, an ideal system never exists.

Before to start analyzing the acquired data it is necessary to analyze the errors in amplitude and frequency introduced on the signal due to the impedance of the passives elements.

The output impedance of the amplifier and the impedance of the coaxial cable were both commented in section 2.1. Now that has been chosen the data acquisition system of our system it is necessary to detail which impedance has been added. The *USB* PropScope oscilloscope introduces input impedance consisting in a resistance (1 MΩ) and a capacitance (20 pF).

As was commented in section 2.1 the output impedance of the amplifier and the input impedance of the *DAS* are fixed. Along this section the actual circuit and also a modification of it will be study; that will consist in changing the coaxial cable by an external divisor probe with the objective to compensate both, the capacitance of the coaxial and the capacitance of the oscilloscope.

2.3.1. Coaxial cable

In order to establish clearly the effects introduced by the impedances. This sub-section will contain two parts: i) the first part will study theoretically the circuit that forms the system; ii) the second part will compare the theoretical study with experimental images extracted from the system.

The objective of a circuit's theoretical study is to find its response in time domain and also in frequency (complex) domain; this feature is called transfer function. The transfer function permits understanding the output signal; and also to see how the input signal changes depending its amplitude and frequency. Then the first circuit studied is shown in the figure below:

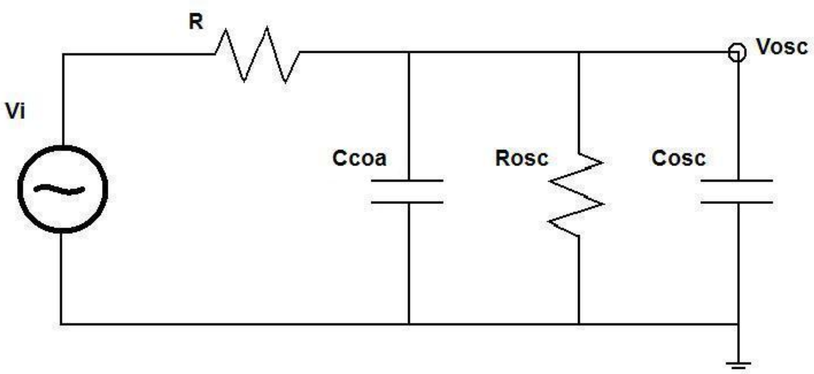

Figure 2.5 Circuit wired with a coaxial cable

To make easy the lecture of the thesis, this section will show a schematic study of the circuit. Annex II contains a deeper explanation, and it also shows and explains all the steps performed.

The first step to do in order to solve easily the circuit is to find an equivalent circuit. Then the equivalent capacitance of two capacitances in parallel is calculated, obtaining an equivalent circuit that works as a voltage divisor. The resistance of the oscilloscope is much bigger (10.000 times) than the output resistance of the amplifier; in consequence the equivalent resistance of the circuit is simply the output resistance of the amplifier (Figure 2.6).

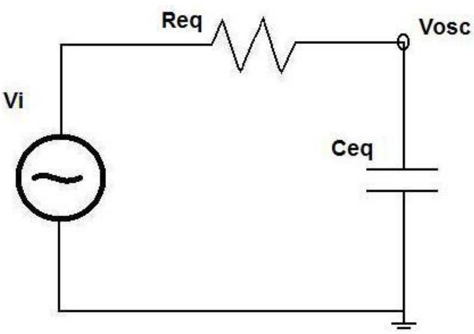

Figure 2.6 Equivalent circuit.

Where the equivalents elements are:

$$C_{eq} = C_{coa} + C_{osc} = 100 \text{ pF} \quad \textbf{(2.2)}$$

$$R_{eq} \overset{R \ll R_{osc}}{\triangleq} R = 100\ \Omega \quad \textbf{(2.3)}$$

The solution of the circuit shown in figure 2.6 is:

$$V_{osc} = V_i - R_{eq} \cdot I \quad \textbf{(2.4)}$$

$$V_{osc} = C_{eq} \cdot I \quad \textbf{(2.5)}$$

Reordering equation 2.4 and 2.5 it is possible to express the relation between the output signal and the input signal (equation 2.6) in the time domain.

$$\frac{V_{osc}}{V_i} = \frac{C_{eq}}{C_{eq}+R} \quad \textbf{(2.6)}$$

To obtain the frequency’s dependence on the signal it is necessary to work in the complex frequency domain. Hence it is necessary to convert the value of each equivalent element by their impedances. In this case it is just necessary to convert the value of the capacitance because the resistance does not have any affect in the frequency domain.

$$Z_{eq} = \frac{1}{sC_{eq}} \quad \textbf{(2.7)}$$

Where $s = jw$ and j is the complex number. Expressing equation 2.6 in the complex frequency domain,

$$T(s) = \frac{1}{1+sRC_{eq}} \quad \textbf{(2.8)}$$

Equation above shows the dependence in frequency of the circuit's transfer function in the complex frequency domain (s). The function has a zero in the denominator that expresses the cut frequency of the circuit. Then the circuit works as a low-pass filter and its cut frequency is:

$$\left|1 + sRC_{eq}\right| = 0 \ \rightarrow f_{cut}^{coa} = \frac{1}{2\pi RC_{eq}} = 15{,}9\ MHz \quad \textbf{(2.9)}$$

The effect produced by the impedance is to introduce different errors in the acquired signal depending on the frequency. And it will also cause the lost of peaks that must contribute to the Photon's energy spectrum; consequently this effect increases the time of acquisition.

To show graphically these effect two square functions with different frequencies will be shown in Figure 2.7 and Figure 2.8, in order to analyze the different effects.

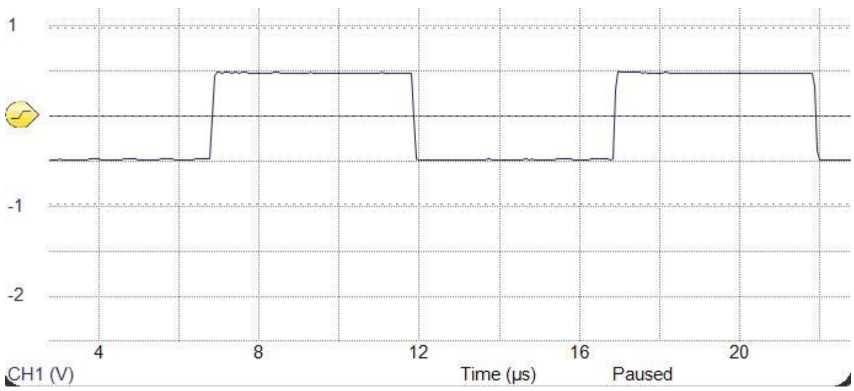

Figure 2.7 Square signal (f=100 kHz, Amplitude=1 V);

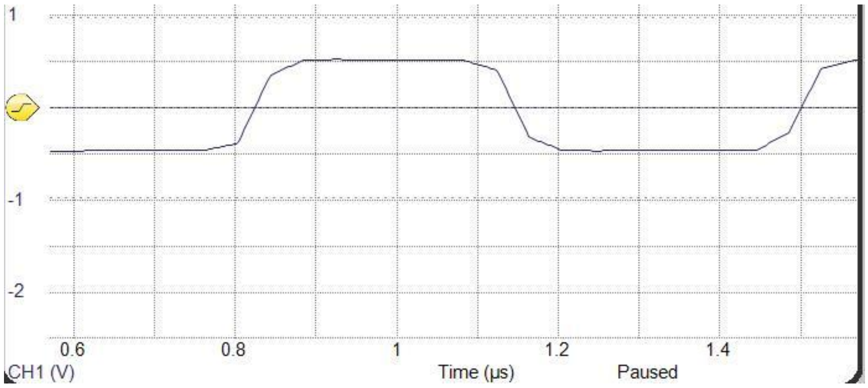

Figure 2.8 square signal (f=1.5 MHz, Amplitude 1 V)

Figure 2.7 and Figure 2.8 shows how the response of the system is. Two features are clearly seen in the figure above: i) exists a ripple effect in Figure2.7 that is produced by an output inductance in the amplifier which value is not present in the manual. This effect will modify the amplitude of the peaks, because adds a ripple on the semi-Gaussian peak. Its effect will be studied at the end of this chapter; ii) the value of the slope in Figure 2.8 is not big enough to recreate the shape of the signal; it will change the shape of the signal.

To do a quantification of the error in amplitude introduced by the impedance, it is necessary to use the transfer function (equation 2.8) in the complex frequency domain, calculate its module and use it in the relative error equation:

$$E_{rel} = \left|\frac{V_i - V_{osc}}{V_i}\right| \times 100 = \left|\frac{1 - \frac{1}{\sqrt{1 + R^2 C_{eq}^2 w^2}}}{1}\right| \times 100 \qquad \textbf{(2.10)}$$

In figure 2.8 it is obvious that the impedance is not compensated; then the system is not able to represent properly the square function.

The time that requires charging a capacitor to 63.2 % of full charge is called time constant, represented by the Greek letter τ; figure 2.8 permits to obtain a first approximation of the time constant:

$$\tau \cong 0{,}06\ \mu s = 60\ ns \qquad \textbf{(2.11)}$$

Once the complex frequency domain has been analyzed, it is worth also to obtain the transfer function in the time domain. It is necessary to use the equation of the transfer function in the complex frequency domain (equation 2.8) and apply the inverse Laplace transform; the result is:

$$\frac{V_{osc}}{V_i} = \frac{1}{RC_{eq}} e^{-\frac{1}{RC_{eq}}t} \qquad \textbf{(2.12)}$$

The transfer function in the time domain shows that for an observed peak, the transfer function applied on the signal is an exponential decay with a discharge time constant:

$$\tau = RC_{eq} = 10\,ns \quad \textbf{(2.13)}$$

Hence if the results of equations 2.11 and 2.13 are compared then the conclusion of this sub-section is that the theoretical and graphical results do not agree. It means that probably the system has some other elements that would affect the data.

Analyzing the equation 2.12 it is possible to conclude that as lowest the value of τ is, is the better will be rebuilt the shape of the signal. Hence the idea is to find an equivalent circuit diminishing either the equivalent capacitance or the equivalent resistance. In this case, it has been explained that the output resistance of the amplifier is fixed; then the solution will be to use an external divisor probe (*EDP*).

2.3.2. External Divisor Probe (EDP)

To reduce the impedance introduced by the amplifier and the oscilloscope an *EDP* is used to wire the system instead of the coaxial cable.

In this case it is just necessary to comment the impedance introduced by the *EDP* because the amplifier and the oscilloscopes are the same (see Figure 2.9).

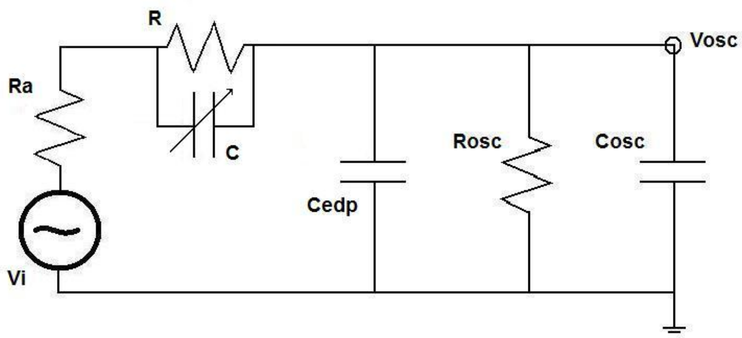

Figure 2.9 Circuit's scheme wired with *EDP*; V_i is the output signal, R_a is the amplifier's output resistance, *R* is the resistance of the *RC* net, C is the adjustable capacitance, C_{edp} is the capacitance of the coaxial cable which forms the EDP, R_{osc} and C_{osc} are referred to the oscilloscope.

The EDP includes a coaxial cable with an impedance commented in the previous sub-section and a RC front circuit with an adjustable capacitance and a resistance of 10 MΩ; it offers a higher input resistance and a lower capacity in parallel than the oscilloscope alone.

The circuit (figure 2.9) will be separate in two parts; the first study will consist in finding an equivalent circuit of the elements that do not belong to the amplifier.

To obtain the equivalent circuit, working in the complex frequency domain it is necessary to calculate the equivalent impedance of the *RC* front circuit:

$$Z_1 = \frac{R}{1+sRC} \qquad \textbf{(2.14)}$$

It is also necessary to calculate the equivalent impedance of two parallel capacitances in parallel with a resistance.

$$Z_2 = \frac{R_{osc}}{1+sR_{osc}C_{eq}} \qquad \textbf{(2.15)}$$

The equivalent circuit is shown in the figure 2.10.

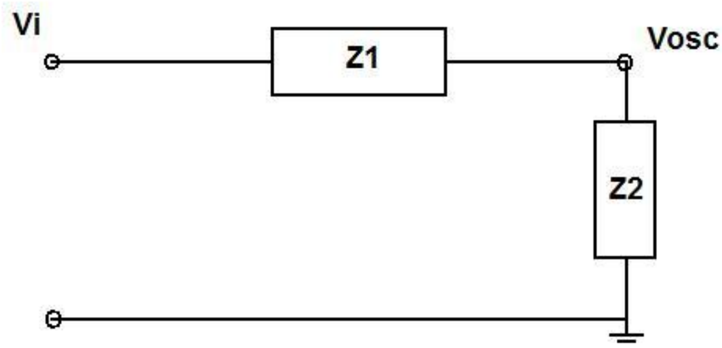

Figure 2.10 Equivalent circuit's scheme with impedance.

At that point, as the equivalent circuit is analogue to that one, it is possible to adapt the expression found in the sub-section (2.6). Although now it is going to be written directly in the complex frequency domain; then substituting *R* by Z_1 and Z_{eq} by Z_2, obtaining directly:

$$T(s) = \frac{Z_2}{Z_2+Z_1} \qquad \textbf{(2.16)}$$

Substituting the expressions 2.14 and 2.15 in the previous equation the transfer function of the system is found:

$$T(s) = \frac{R_{osc}}{R_{osc}+R\cdot\frac{1+sR_{osc}C_{eq}}{1+sRC}} \qquad \textbf{(2.17)}$$

The condition that satisfies the *EDP* when it is compensated is:

$$R_{osc}C_{eq} = RC \tag{2.18}$$

It justifies that C must be adjustable because each oscilloscope has different resistance and capacitance.

In the PropScope case, the compensated value for C is:

$$C = \frac{R_{osc}C_{eq}}{R} = \frac{C_{eq}}{10} = 10\ pF \tag{2.19}$$

Returning to (2.17), and assuming (2.18), the transfer function is:

$$T(s) = \frac{R_{osc}}{R_{osc}+R} \cong \frac{1}{10} \tag{2.20}$$

This result, as was expected, means that this part of the circuit does not affect to the measure data in frequency. In amplitude, data are attenuated by factor *10*. Applying the inverse of the Laplace transform to the expression 2.20 the transfer function in the time domain is obtained:

$$V_{osc} = V_i \cdot \frac{R_{osc}}{R_{osc}+R} = \frac{V_i}{10} \tag{2.21}$$

This factor is corrected by the oscilloscope's software because exists an option to setup the probes.

Using the admittance it is possible to find the values equivalent to the capacitance and resistance. Then to work with admittance, first it is necessary to calculate the total impedance:

$$Z_{total} = Z_1 + Z_2 = \frac{R_{osc}+R}{1+jwR_{osc}C_{eq}} \tag{2.22}$$

And the admittance is:

$$Y = \frac{1}{Z_{total}} = \frac{1}{R_{osc}+R} + jwC_{eq} \cdot \frac{R_{osc}}{R_{osc}+R} \tag{2.23}$$

Therefore the system acts as an equivalent resistance and an equivalent capacitance in parallel with the following values:

$$R_{eq} = R_{osc} + R \cong (10)\ M\Omega = 10\ M\Omega \tag{2.24}$$

$$C_{sys} = C_{eq} \cdot \frac{R_{osc}}{R_{osc}+R} \cong \frac{100\ pF}{10} = 10\ pF \tag{2.25}$$

Hence the equivalent circuit is shown in Figure 2.11. As was commented at the beginning of the sub-section, the equivalent system has a bigger input resistance, and a smaller capacitance than the case of the coaxial cable. Although both are analogues; taking profit of this fact, only the key expressions in the analysis of the circuit will be shown. For further explanations, see Annex II.

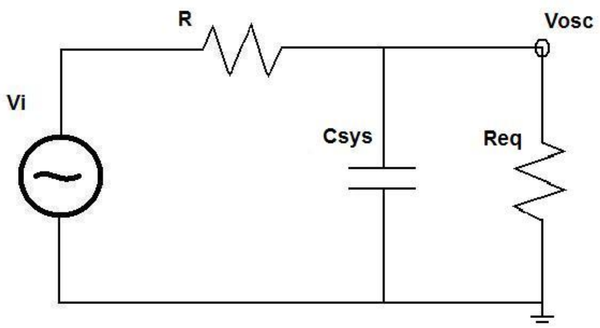

Figure 2.11 Scheme of equivalent circuit wired with EDP.

Accordingly the transfer function is (2.8):

$$T(s) = \frac{1}{1+sC_{sys}R} \tag{2.26}$$

It is dependent on frequency (as it is in 2.10), but in that case the value of the cut's frequency is:

$$f_{cut}^{EDP} = \frac{1}{2\pi RC_{sys}} = 10 \cdot f_{cut}^{coa} = 159\ MHz \tag{2.27}$$

It is a great improvement, because just changing the wire type the system is able to obtain data with a frequency ten times bigger without being modified. It means that the peaks with higher frequency will be detected with this wire. A table with this feature of the system is shown in Annex II.

To find the transfer function in the time domain, the expression found in the previous sub-section is going to be used (equation 2.12) with the only change of C_{sys} instead of C_{eq}. Obtaining:

$$\frac{V_{osc}}{V_i} = \frac{1}{RC_{sys}} e^{-\frac{1}{RC_{sys}}t} \tag{2.28}$$

Finally, as was explained in the section 2.3.2, the peaks with equal or higher frequencies than the cut frequency, will be modified in amplitude as (analogous to equation 2.10):

$$E_{rel} = \left|\frac{V_i - V_{osc}}{V_i}\right| \times 100 = \left|\frac{1 - \frac{1}{\sqrt{1+R^2 C_{eq}^2 w^2}}}{1}\right| \times 100 \qquad \textbf{(2.29)}$$

2.4. Complete circuit

Once we have decided which type of wiring we will use, it is the moment to introduce in the circuit analysis the effect due to the amplifier's inductance that has been commented in the previous section.

The output inductance value is not in the user's manual of the amplifier, then the best option to find its value is to measure the Bode diagram of the whole system and compare it with our ideal system (Figure 2.12); it means to introduce a known input signal to the amplifier (sinusoidal) and measure for each frequency how the signal changes.

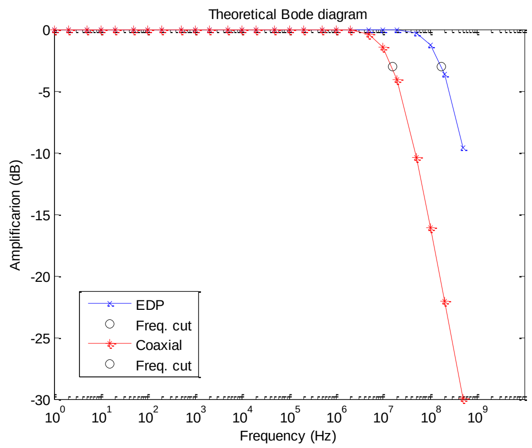

Figure 2.12 Theoretical Bode diagram, and cut frequency (black circle).

The figure above represents in different colours the qualitative shape of a Bode diagram for a coaxial cable and for an external divisor probe. As was calculated in section 2.3.1 and also in section 2.3.2, the theoretical results show that the cut frequency is higher for an EDP than for a coaxial cable.

In order to measure the real Bode diagram of the system, it is necessary to calculate what the working area of the signal is over the frequency domain.

In previous section 2.2.2, was commented the main feature of a peak. Then in order to obtain the two slopes which define us the area of work in the frequency domain, it is necessary to find the maximum and the minimum amplitude of a peak without overlap and divide its amplitude by the time duration, which could be approximated for the time passed between two points and a half of this time (looking table 3.1, we can conclude that for TS of 100 µs, this time will be 3 µs). Consequently the range of working frequency it is calculated as follow:

$$slope = \frac{Amplitude}{\Delta t} \quad \textbf{(2.30)}$$

The following graphic (Figure 2.13) shows the real Bode diagram for both wiring types, EDP and coaxial over all the frequencies.

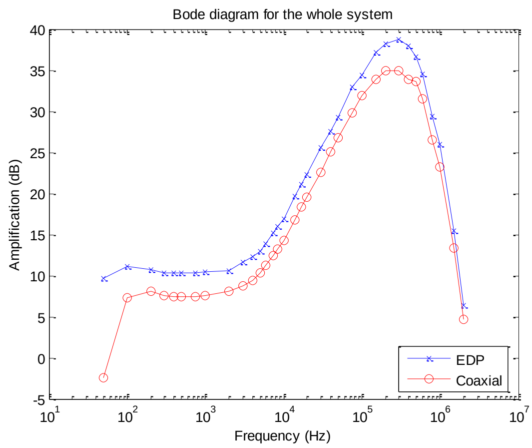

Figure 2.13 Bode diagram for EDP and coaxial cable.

First of all, it is possible to conclude that the system is not a low pass filter, as we supposed at the beginning. It means that there are some more passives elements that we are not considering and also that the amplifier not only works as an amplifier but it also works as a differentiator.

We can conclude that there exist four reactive elements that provoke two zeros in the system response: one positioned around 50 *Hz* and the other one around 2 *kHz*; and also two poles: one located around 100 *Hz* (single pole) and the other one around 200 *kHz* (triple pole). As a consequence it is not possible to fix what the real elements of the whole system are (in our case just for the amplifier). Due to the semi-logarithmic scale used in the Bode diagram it is not easy to distinguish between the results obtained for the coaxial cable and the EDP.

In order to get more information about how our system works it will be worth to observe the Figure 2.14 that express the system response in a linear scale.

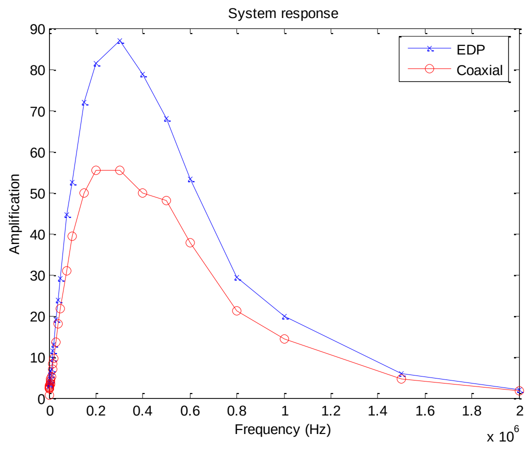

Figure 2.14 System response of the whole system for different wiring type (linear scale x-axis).

In Figure 2.14 it is clearer than the cut frequency for coaxial cable (around 200 *kHz)* is smaller than the cut frequency for EDP (around 300 *kHz*). As a consequence, we can confirm that, although the unknown passive element modifies the cut frequency in both cases, it does not change that the best option to wire our system is the EDP.

The total range area will be calculated using two peaks: one of the minimum amplitude and one of the peaks with maximum amplitude (see Table 2.2):

Table 2.2 Frequency working range of the signal (using $\Delta \boldsymbol{t} = \mathbf{3}\boldsymbol{\mu s}$).

Amplitude (V)	*Frequency*
0.1	≈ 34 *kHz*
6	≈ 1.6 *MHz*

Once the complete Bode diagram is understood, Figure 2.15 will show the Bode diagram in the signal frequency range.

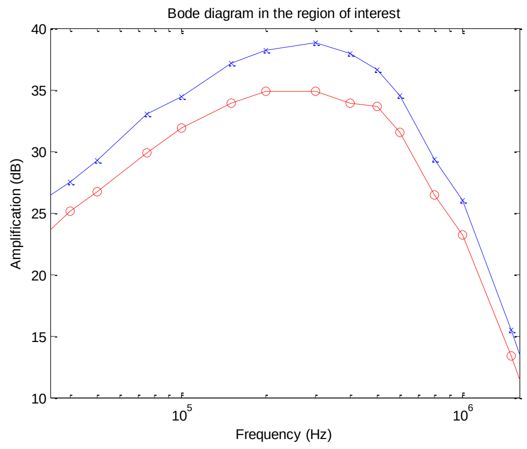

Figure 2.15 Bode diagram over region of interest

In order to obtain more information, we are going to calculate in table 2.3 where are located the peaks with its energy inside the energy window filter.

Table 2.3 Frequency range for peaks around 14.4 keV

Amplitude (V)	*Frequency (MHz)*
0.5	≈ 0.16
1	≈ 0.33

If we compare the results obtained in Table 2.3 with Figure 2.15 it is possible to observe that the peaks around 14.4 keV are in frequencies around the maximum amplification (see Figure 2.16).

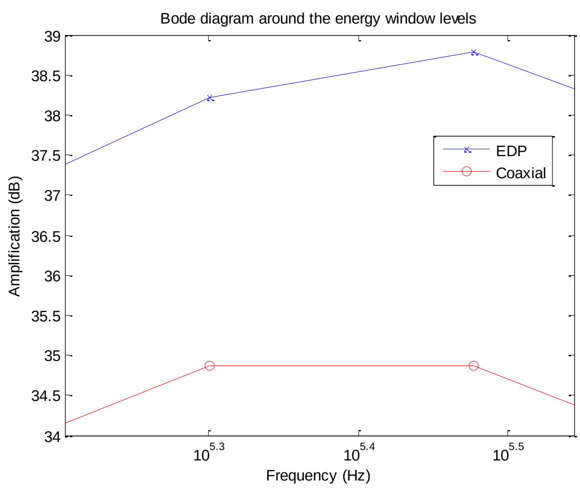

Figure 2.16 Bode diagram in the region determined by the energy window

Figure 2.16 is very interesting, there it is possible to appreciate three key features: i) the EDP amplifies more than the coaxial cable the peaks which important information for the Mössbauer experiment; ii) the peaks more amplified are the ones who satisfy the conditions (energy range) imposed by the energy window and finally iii) comparing it with Figure 2.15, it is possible to conclude that, over the region where appear the three main peaks of the source (6,4; 14.4, 21) keV the amplifier works approximately linear.

As was said before, the amplifier is working also as a differentiator, it means that when the amplifier receives a pulse, first of all it derivates the pulse and amplifies it; then finally on the negative area is superposed a near-Gaussian form (it allows to obtain information over the dead time. In order to get an example of what differentiator does, see Figure 2.17.

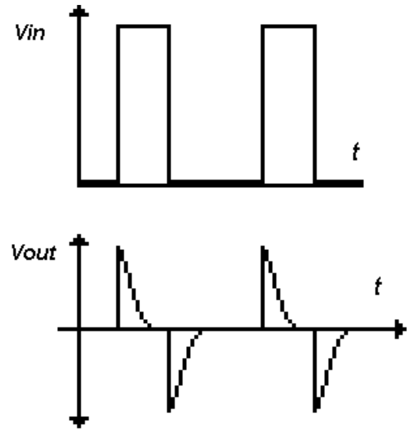

Figure 2.17 Amplifier-Differentiator.

2.5. Conclusions

As a conclusion of this chapter, it is worth to make a simple summary.

In section 2.2 we discussed about which acquisition system will be our best option evaluating features against cost. It was an easy decision because the difference of cost was huge between a DAQ device and the oscilloscope (around ten times cheaper). Although it means that our system will be slower.

At the end of the section it was presented the conclusion about the oscilloscope’s features: (i) 10 bits, (ii) At least 0,5 Msample/sec.

In section 2.3 it was made a theoretical study between wiring our system with a coaxial cable (as was before the project) or with an external divider probe (*EDP*).

The theoretical study was clearly favourable to *EDP* because, although both connexions make to work the system as a low pass filter, using *EDP* increases the cut frequency more than 10 times. It permits to obtain four times more peaks with the

same time sampling (see Annex II). It means that although our system is going to work slower than the data acquisition system with its commercial software used before the project, we are able to decrease in four time our acquisition time in comparison with the time necessary to obtain the same statistics with a coaxial cable.

Considering the information obtained thanks to the analysis of the system's response, it is possible to conclude that the amplifier not only works as a linear amplifier but also as a differentiator which causes that the whole systems response is a pass band filter.

Finally, it is concluded that the peaks around 14.4 keV, which are those necessary for the MS are located around the maximum amplification over the frequency domain.

Chapter 3

PREVIOUS NUMERICAL DATA TREATMENT WITH MATLAB

Since the beginning of the project we thought that could be possible to obtain the spectrum of the radioactive sample using the peak that has a near-Gaussian shape instead of the peak that is similar to a Dirac's delta. We also thought that the information about dead time could be obtained first, detecting all the peaks, and then impose an overlapping condition to remove the peaks overlapped.

Finally we realize that the most reliable way of work should be the ones presented in Chapter 3. Then in Annex V will be shown the first work done in order to obtain a histogram with the peaks that have a near-Gaussian shape.

In this chapter it is explained how was the process to create the MatLab code with a wide explanation about its highlights; the idea is to focus into the mathematical idea of how to treat this kind of signal.

First of all, it is interesting to say that the platform used to make the first code was MatLab. The reason is that LabView (LV) has as a tool a MatLab script that allows us to insert the previous code almost directly to LV.

The full code is presented in Annex IV; it contains commentaries about the idea behind each important step.

In Chapter 3 is going to be shown how the data were treated, including images to make it more visual, allowing the reader to understand what was the author's idea doing each step.

The first stage of numerical treatment, once the oscilloscope was bought and available in the laboratory, was to determinate how it works i.e.: sampling frequency (f_S), data transfers, clipped effect, etc.

The final step was to acquire data and starts to create the code in order to start obtaining the first amplitude's histogram and information about the dead time.

3.1. Characterization of oscilloscope's data acquisition system

With the oscilloscope's software installed on the computer, the first step was to analyze how it works, for instance: (i) which sampling frequency (f_S) is used and how it changes when the time scale (TS) is changed; (ii) how the oscilloscope transfers data into the computer; (iii) how the oscilloscope works when the signal is clipped.

3.1.1. Sampling rate and time scale

The USB Propscope oscilloscope has a f_S up to 25 Msamples/s; although all digital low-cost oscilloscopes samples the input data at fixed rates depending on its time scale. The cost to be working in a low cost project is that the analogue to digital convertor is not as good as could be. The consequences are that the analogue to digital convertor is not as fast as we wished, then the internal memory of the oscilloscope is not as big as would be wished and consequently the transfer data velocity is also very limited.

Fortunately this project pretend to create an application that will be used once in few months, when is necessary to check the position of the amplifier energy window; that is the reason why the project is going to be very useful although it has technical limitations.

As was commented in the introduction of the chapter, it is necessary to understand how the digital oscilloscope works. For this reason it is essential to distinguish between the two modes of work.
On one hand if the TS is slow enough (bigger than 20ms/div) to continuously send all samples over the USB connexion, then the PropScope goes into streaming mode, where it is possible to see all samples moving from right to left.

On the other hand, when the TS knob is to set into faster TS, the scope takes a set of samples and transfers them to be displayed. The sampling rate (SR) is calculated to return twenty divisions of data over 1024 samples; in consequence it is necessary to make a balance between the maximum TS possible against the idea to obtain the full peak inside the 1024 samples vector.

The following table shows the correspondence between SR, TS and the time acquired in one 1024 sample vector:

Table 3.1 Dependence of the time acquired in a vector against SR, TS.

SR (Msamples/s)	*TS (µs)*	*Time acquired (µs)*
25	2	40
10	5	100
5	10	200
2,5	20	400
1	50	1000
0,5	100	2000

Looking on the table 3.1 and taking into account that the maximum amplitude peak, it means around 5 V, (see Figure 3.1) is around 40 points, equivalent to 80 µs width, it does not have too much sense to use a TS faster than 100 µs (because if not, we will lose information about the dead time); it probably could cut any peak by the half

losing its information. In addition looking the figure below it can be concluded that the parameter of the amplitude is well measured.

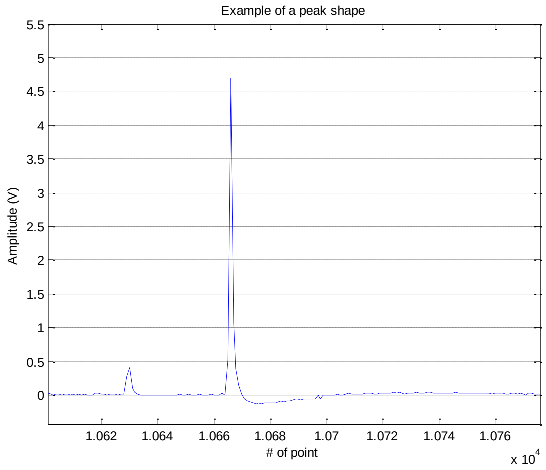

Figure 3.1 The width of this peak is around 40 points, it means 80 µs.

3.1.2. Transfer data velocity

USB PropScope hardware like all digital instruments puts limitations on what can be done. Main issues are: PropScope analogue to digital convertor velocity, memory size and USB connexion speed.

These features translated to our system means that exists a limited transfer data velocity; in that case it is 35Kb/s (low although in consequence of its cost).

For example in order to obtain a file which size is 22,352 KB, PropScope took twenty minutes approximately.

3.1.3. Clipped signal

When a signal exceed the amplitude allowed (10 V_{pp}) by the oscilloscope it is said that the signal is clipped; in this case PropScope just remains with the maximum value permitted until it starts to descends when the signal value is lower than 10 V_{pp}. It does not produce any kind of problem, it just saturate the signal during the time that the signal exceeds the maximum value allowed.

3.2. MatLab code

In the introduction (chapter 1) was explained which where the goals of the master thesis; the main one is to create a code that makes the histogram of the emitted

peak's amplitude (Photon Height Analyzer) and to get information about the dead time of the detector.

The complete code is shown in Annex (IV); in this section the code will be explained step by step, focusing on the main ideas that allow analyzing the signal properly.

3.2.1. Reading data

This section is divided in two sub-sections because is going to be worth to understand the signal obtained through two different outputs.

On one hand, a long data file will be acquired from the amplifier's unipolar output in order to obtain the total spectrum of the radioactive sample.

On the other hand, a data file (shorter than the previous) will be acquired from the energy window output in order to obtain the peaks that accomplish the condition imposed on the energy by the filter.

In Figure 3.2 it is shown as a example the signal's shape using directly the output data of the amplifier obtained from the oscilloscope with the goal to observe that the PropScope acquire data packs of 1024 sample length and then the next pack starts again at zero point.

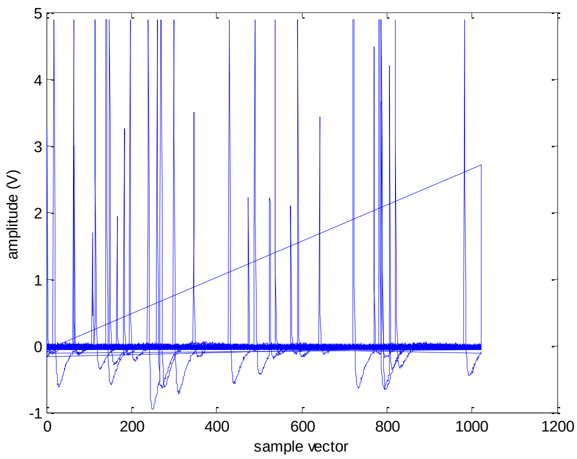

Figure 3.2 Shows that position vector goes between 0 and 1023

As a consequence it is needed to spread out the position vectors in one longer vector, obtaining the result shown in the Figure 3.3:

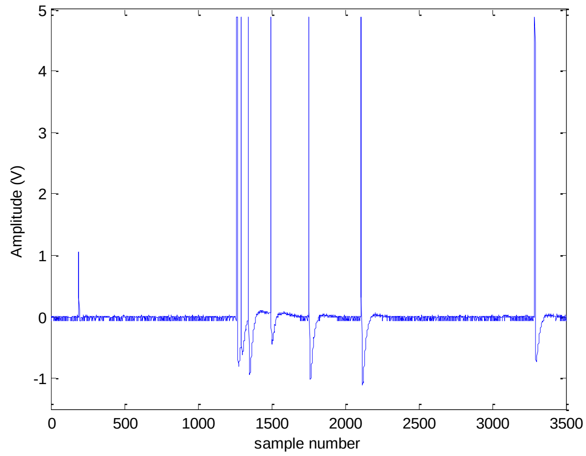

Figure 3.3 An example (some packs of 1024 points) of the previous position vector spread out

3.2.2. Peaks detection over amplifier's output data

To understand the signal shape obtained from the amplifier's unipolar output, it could be observed Figure 3.3. There, it is shown that the peak consist in a fast increment of voltage (from 2 µs until 6µs maximum), followed by a negative near-Gaussian peak, which allow us to obtain information about the dead time.

The MatLab code pretends to find the position and amplitude value of the positives peaks. In order to know how to detect the positives peaks it is essential to know their features, therefore the data will be zoomed to obtain some key parameters (see Figure 3.4).

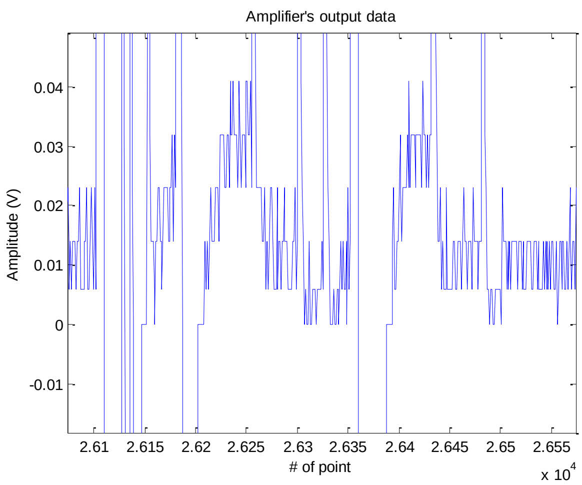

Figure 3.4 Signal without values greater than 50 *mV* (excepting peaks).

Then to characterize basically the signal, there exists to different behaviours: (i) when there is not emission, the signal remain around zero with a minimum value of 0 V and a maximum value of 50 mV very well determinate (see Figure 3.4); (ii) when there is a peak to detect the values are over this 50 mV.

As the objective is to determine the peaks due to emission process, the region (i) allows determining properly the minimum value accepted to consider a peak as a maximum; Using a 'for' loop and applying the condition expressed in equation 3.1:

$$y(i) > 0.05 \ \& \ y(i) - y(i-1) > 0 \ \& \ y(i) - y(i+1) > 0 \qquad \textbf{(3.1)}$$

The only step to perform later on is to remove over the position and amplitude vectors and the positions with zero value that do not accomplish the condition. Then all the peaks will be detected without removing the overlapped ones (see Figure 3.5).

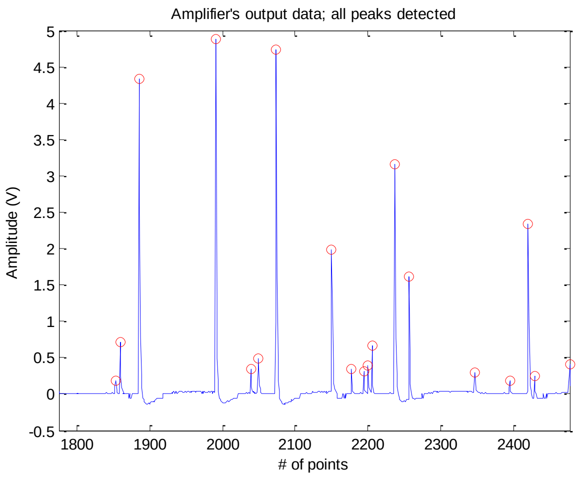

Figure 3.5 Amplifier's output data with all the peaks detected

3.2.3. Peaks detection over the energy window output data

In Figure 3.6 it is possible to observe that the function of energy windows is to discriminate the peaks, distinguishing the peaks received from the amplifier unipolar output that are inside of the energy window value from the peaks that are not.

When the discriminator receives a peak with its energy inside the values permitted by the energy window, then appears a kind of Dirac's delta synchronized with the position of the desired peak on the amplifier's output data file; if it is not, then the output signal remains constant in a value near to zero.

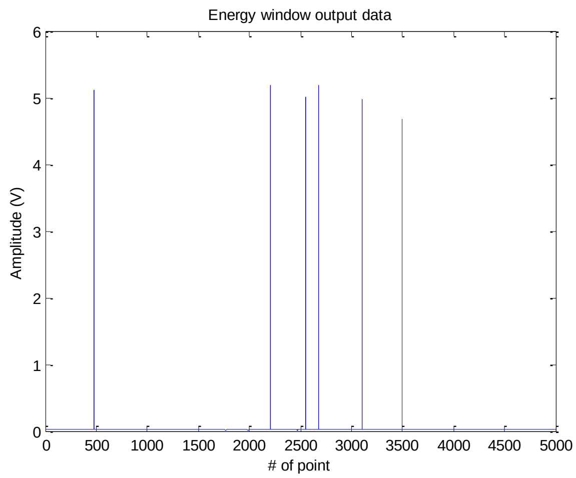

Figure 3.6 Energy window output data

As was done in the previous sub-section 3.2.2, it is interesting to observe zoomed the signal (see Figure 3.7).

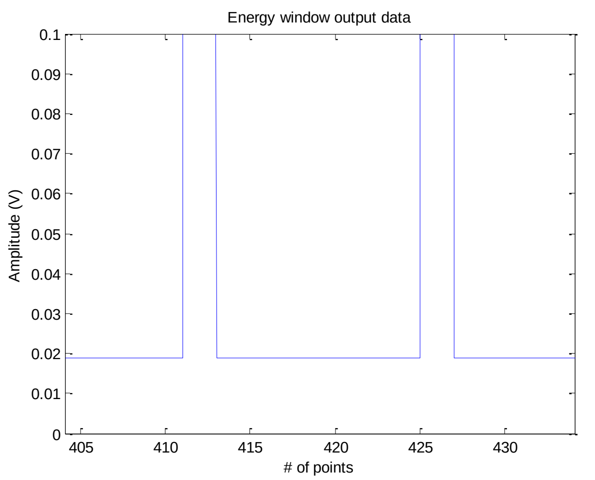

Figure 3.7 Energy window output data zoomed

The energy window output data is very well defined; it is possible to observe two situation: a) if there is no peaks with the energy between the upper and lower limit the signal remains constant with a value of 19 *mV*; b) the energy window receives a peak with its energy between its limits, then the signal has a value around 5 V.

Then in order to know the proper value of the peak, it is necessary to take profit of the synchronization between the amplifier's output and the energy window, as could be observes in Figure 3.8; in this figure it is changed the value of 5 V by 0.5 in order to obtain a clearer image.

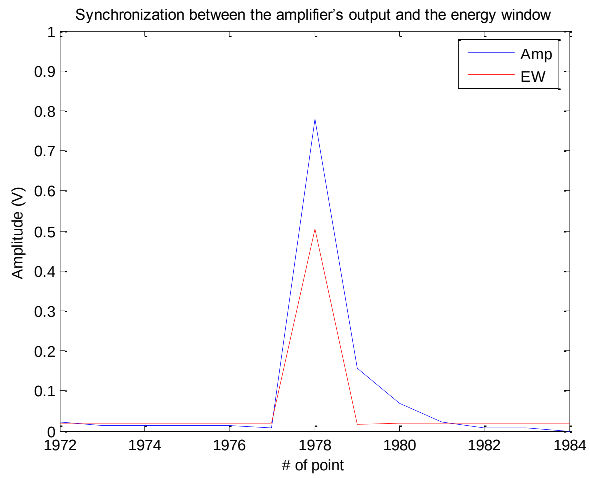

Figure 3.8 Example of synchronization between amplifier and energy window output

This condition will make easier to detect the peak's position, because once it is detected the peak over the energy window output, it is just necessary to use its position and find in the amplifier's unipolar output what the amplitude of this point is.

Figure 3.9 shows the selected peaks by the energy window detected.

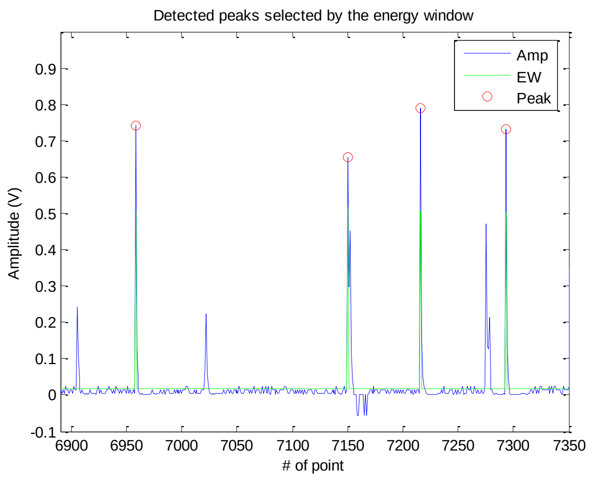

Figure 3.9 Detected peaks selected by the energy window

3.2.4. Overlap

In order to detect if one peak is overlapped or not, it is necessary to remember how the behaviour of the peak is. This description can be found at the beginning of the section 3.2.2. The feature that it is going to be used is that the peak will last as maximum 6 µs, in consequence will take as much two points before the maximum value. Therefore, the idea to detect overlap is to analyze the previous two points of a maximum and then to look out if at least one of them belongs to the area delimited by

the condition of dead time (will be explained in the following section); the condition is shown in Annex IV, where can be found the whole code.

In other words, the objective is to analyze if when the peak starts, the signal is modified by a previous peak or remains around their regulars values (given by the noise level on the signal). It is worthy to remark that this condition works both data output, either received from amplifier or energy window. As a example, Figure 3.10 will show a peak overlapped avoided by the condition from the amplifier's output data.

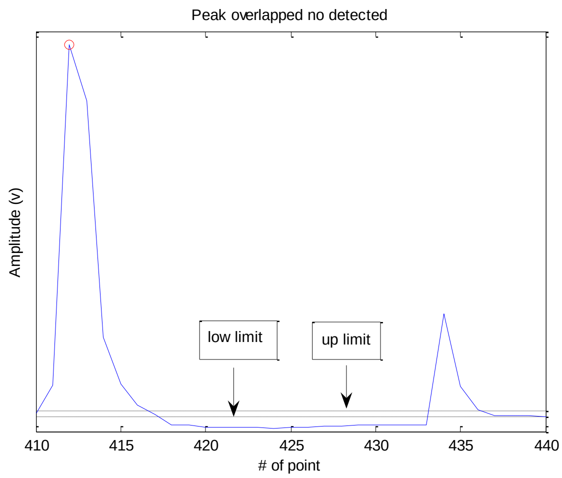

Figure 3.10 Peak overlapped no detected

Observing the previous two points of the peak located in the point 434, we can see that both are located in the area where the detector cannot identified properly the energy, consequently the code avoid the detection of the peak.

3.2.5. Dead time

One key parameter of the program is to give an idea of how the dead time of the system is; in other words, to know if the distance between the radioactive source and the sample to analyze is optimum.

On the one hand if the source is too close to the sample, then the detector will receive a number of photons too big to be able to have a good response; in consequence, the information of the photons will be overlapped; it means that the second photon arrived to the detector will contribute to the histogram with a wrong energy quantity.

On the other hand, if the distance from the source to the sample is too big, a fraction of the information could be lost, because the photons emitted by the source will not impact on the sample.

It is easy to understand that the worst option of both is to have the set up explained in the first case, where the source is too close to the sample. Then, for avoiding counting this photons in the histogram with their modified energy, the program incorporates an option that could be used when the user decide. In order to explain this idea easily, it is important to know how is the behaviour of the data when appears an emission peak.

In order to know which the energy limits are, where a photon could be detected with its correct energy, it is necessary to look the Figure 3.4. As was commented below that figure, it is possible to observe that the upper limit is 35 *mV* and the lower limit is 0 *V*. Then to obtain the percentage of dead time of the detector, it is necessary to use the equation below:

$$t^{dead} = \left(\frac{(35\ mV > \#\ points\ with\ V) + (0 < \#\ points\ with\ V)}{total\ \#\ of\ points}\right) \times 100 \qquad \textbf{(3.2)}$$

3.2.6. Histogram

It is known that MatLab contains a function that creates by itself a histogram. Consequently in this subsection the different histograms of interest will be shown.

Following the order of this chapter, the first histogram to comment is the one which contains all the peaks received from the amplifier's data output (Figure 3.11).

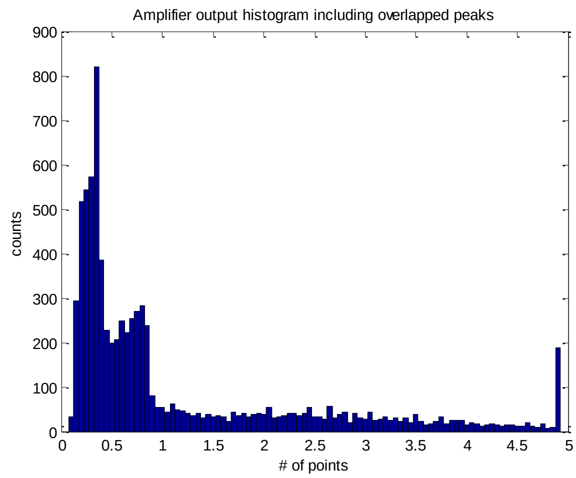

Figure 3.11 Amplifier output histogram including overlapped peaks

Observing figure above, it is not too clear where are located the three peaks required. It is supposed that around 0.35 V exists one (6.4 keV), around 0.7 V maybe exists the second one (14,4 keV), but the third one is really complicated to find it.

In order to obtain a clearer histogram, the Figure 3.12 will remove all the peaks overlapped.

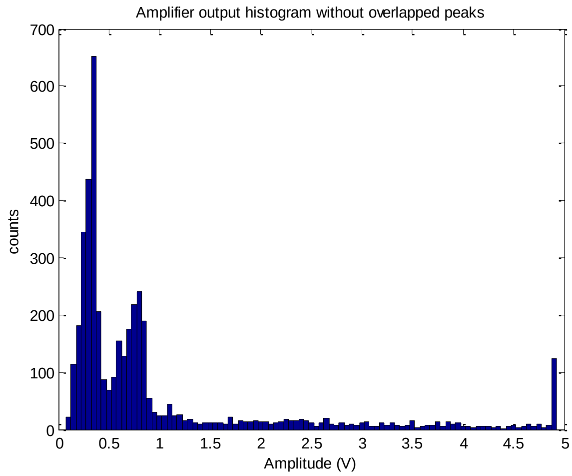

Figure 3.12 Previous histogram without overlapped peaks

Figure above confirms us that the first two peaks are really the peaks that we chose, and it is possible to identify the third peak passed 1 *V.*

In order to confirm our supposition about the position of the peaks, it is going to be shown in Figure 3.13 the peaks selected by the energy window output.

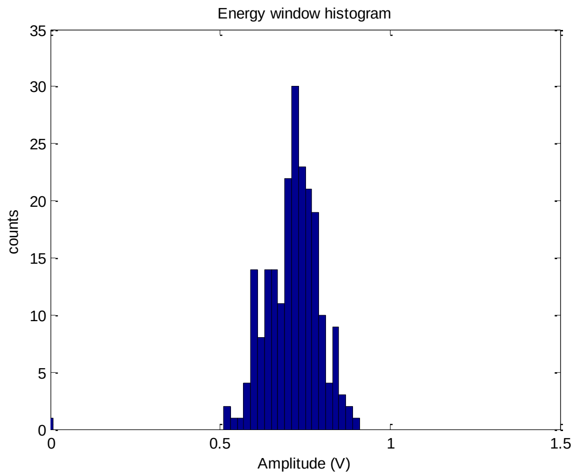

Figure 3.13 Energy window peaks selected histogram

Definitively it confirms us that the peak that is situated around 0.75 V. This conclusion is clearer when superposes in the same histogram the peaks of the Figure 3.12 with the peaks of the Figure 3.13, and comparing this result with the Figure 3.12 (see Figure 3.14).

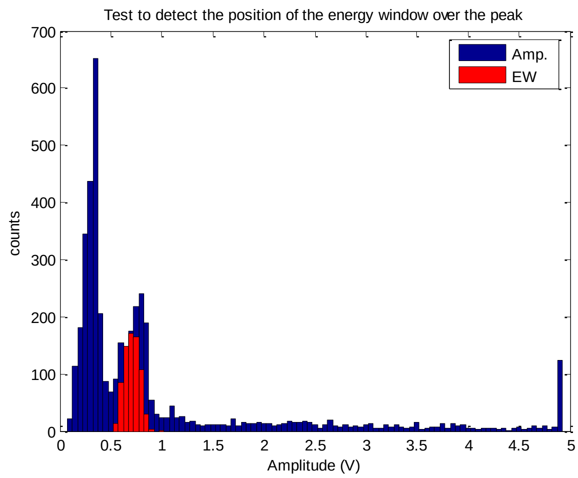

Figure 3.14 Comparison between the histograms obtained by the amplifier and the energy window

3.2.7. Conclusions

This section is dedicated to emphasise some conclusions obtained during the elaboration of this chapter and also to makes some comment about the set up.

Along the chapter we have concluded some values that is going to be used by the USB oscilloscope such us sampling frequency (0.5 Msamples/s) and transfer data velocity (35 KB/s).

It has been also determined some other parameters necessaries for the right work of the code such us the minimum value accepted for a maximum peak detected (50 *mV*) and the threshold values to measure dead time ($V \in [0\,, 35\; mV]$ to avoid dead time).

On the theoretical point of view, it is essential to comment that this chapter explains the condition imposed over the data for avoiding overlap to obtain the peaks that pass through the energy window and some tips to understand properly how the MatLab code works.

As a corollary, it is considered important to comment that every new set up done on the system, the user should check that the USB oscilloscope acquire correctly the data. Because we found in some cases that the oscilloscope was not able to give the desire data accuracy for the measure of the dead time. When this happens, it is necessary to increase the amplification over the input signal.

Chapter 4

LABVIEW PROGRAM AND DISPLAY

In this chapter the creation of the LabView software is explained, commenting all the difficulties appeared during its evolution from the beginning until the end; it will also explain all the options that the display offers and how to use it.

The LV software is divided in three parts: 1) data acquisition, 2) data treatment and 3) display; they will be explained in three different sections.

The first section explains how LV acquires the data from the USB oscilloscope and their previous treatment.

The second section analyze the main data treatment, it means to go a step further to understand the changes over the MatLab code and how will be displayed the final histogram.

Finally, the third section will show the final display and will explain some tips to use it correctly.

4.1. Data Acquisition

The first decision to take at the beginning of the code is to decide how we should acquire the data from the digital oscilloscope. The decision was pretty simple; the best option possible was to create a dynamic data exchange (DDE) between the LV and the digital oscilloscope, which should allow us to acquire data point by point or also acquire packs of 1024 samples (see Annex IV). The digital oscilloscope accepts this way of work (the manufacturer ensures us that was possible to establish a DDE between PropScope and LV).

In order to check the LabView clock (maximum sampling frequency of 1 MHz), we tried to acquire data point by point. It is possible to observe the results comparing Figures 4.1 and 4.2 where are shown the generated square signal (Figure 4.1) and acquired with LV (figure 4.2). It is so clear that working at this sampling rate the digital oscilloscope is not able to rebuild properly the signal generated; in conclusion LV does not work fast enough.

Consequently we decide to work in streaming mode, this solutions seems very fair, because we choose the sampling frequency in order to do not cut the peaks during the 1024 points pack. Then for our purpose it is a good option to acquire packs of 1024 samples even although the packs are not consecutive.

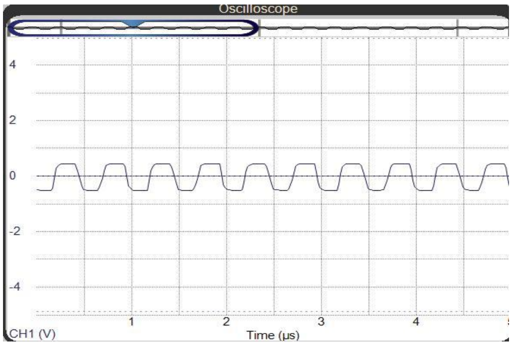

Figure 4.1 signal generated, 2 MHz frequency, 1 v_{pp}.

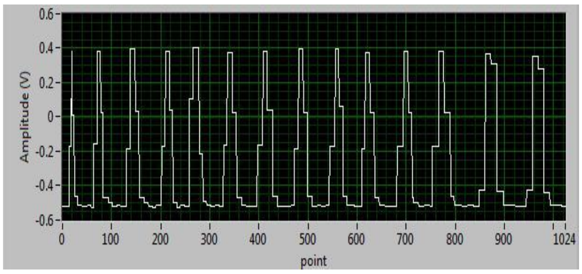

Figure 4.2 Square signal acquired point by point with LV

The problem appeared when we tried to use it; the data packs were acquired correctly but they were not scaled and calibrated (see Figure 4.2 and Figure 4.4).

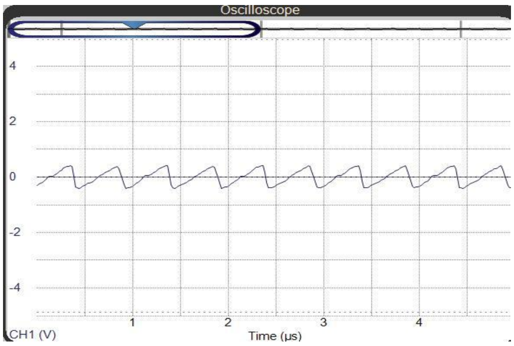

Figure 4.3 Sawtooth signal generated, 2 MHz frequency, 1 v_{pp}.

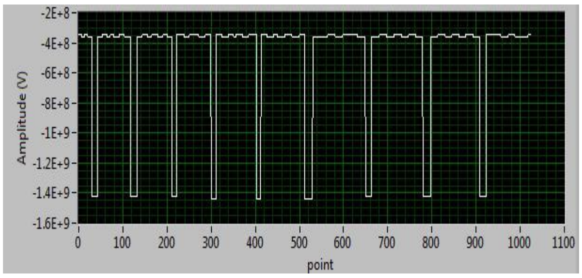

Figure 4.4 Signal acquired in streaming mode with LV.

In order to solve this problem we ask to the company contact, and the answer was that in few days we will receive the PropScope software modified and ready to work (because it was proprietary software). But they do not contact us anymore; even they do not reply the e-mails sent.

As a consequence, the final idea was to forget the idea to work with the DDE and to save the data in a file, and then work over this data file.

Figure 4.5 shows the first part of the LV code. Through the path file it is possible to call the data file, then the program open the file, measure the size of the file and finally identify every sample as a number with its format through a while loop and send as an array with four rows data ready to work (number of point, time, channel 1 and channel 2). Finally the program closes the data file.

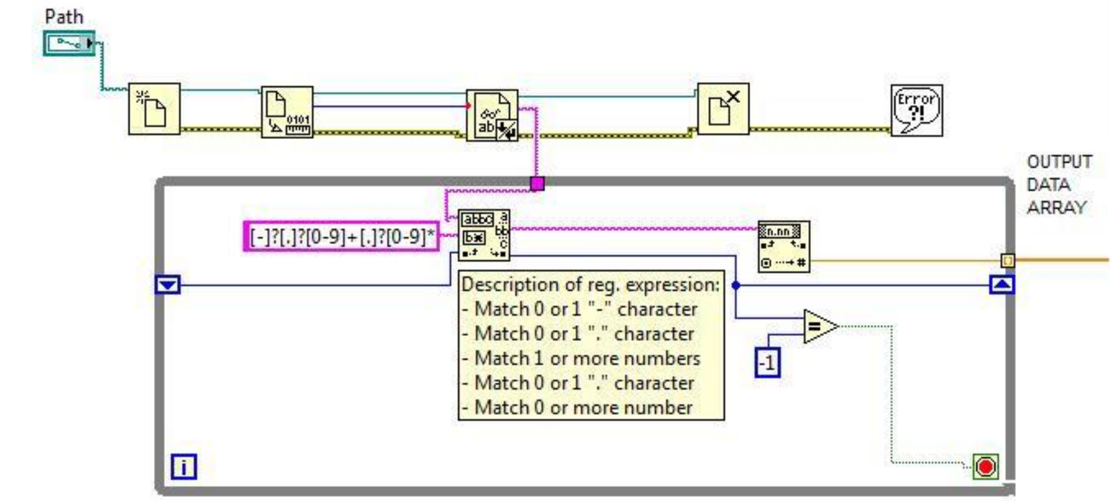

Figure 4.5 Data acquisition with LV

The next part of the code is dedicated to prepare the x axis (time in microseconds) because the data format is prepared to starts in zero at each new pack. Getting the third row of the file (at code appears as a 2 because it starts to count since 0) the y axis (amplitude in Volts) is obtained, and then the data are ready for being used in the MatLab script.

In order to have *time* as a x axis the code place the first pack in a new array; for the others packs the idea is to obtain the last value of the previous pack, and add this quantity plus 2 µs (because the pack starts at zero and the mean time separation between points with this time scale is 2 µs) to the complete pack.

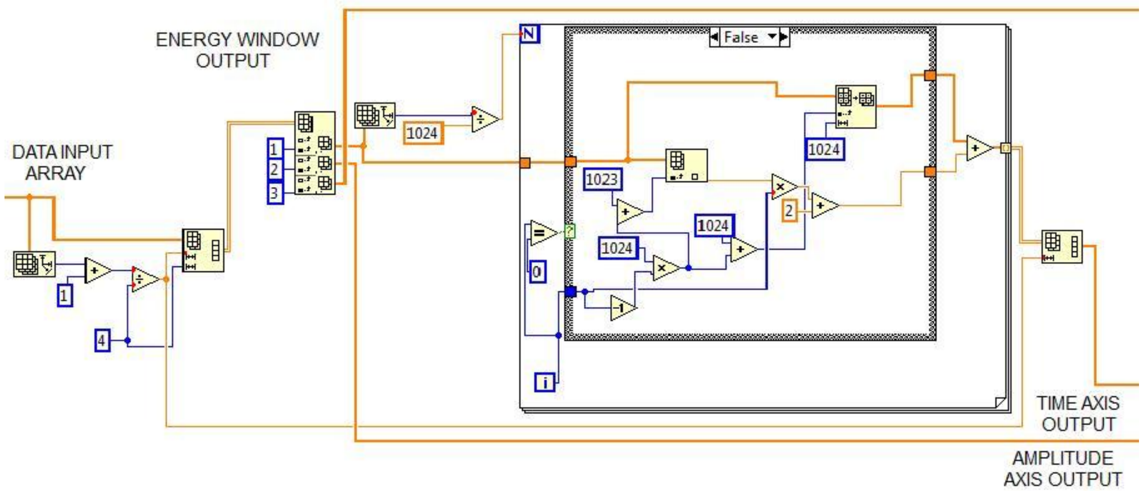

Figure 4.6 Creation of the time axis, and obtaining the amplitude axis.

4.2. Data Treatment

The objective of this section is basically to explain the few small corrections done over the MatLab previous code due to the goal to take profit of all possible LabView's skills. These changes could be essentially expressed in one section: The final histogram: is it the first?

4.2.1. Histogram

The final objective of this thesis is to be able to identify and decide if the energy window is well placed along the energy axis in order to work exclusively with the photons with 14.4 keV energy.

In order to be able to show a graphic with its x axes in energy units it will be necessary to acquire twice data files: a) the first time the display will show an histogram statistically significant with its x axis in voltage; b) the second time the display will show an histogram with the previous peaks and also with the new ones, which will be only those that would pass through the energy window. This step will also calculate the linear equivalence between voltage and energy in order to have the peaks value expressed in energy units ready for the histogram.

4.2.1.1. Histogram pattern (true case)

Figure 4.7 shows the code done for the case that we are acquiring the histogram statistically significant.

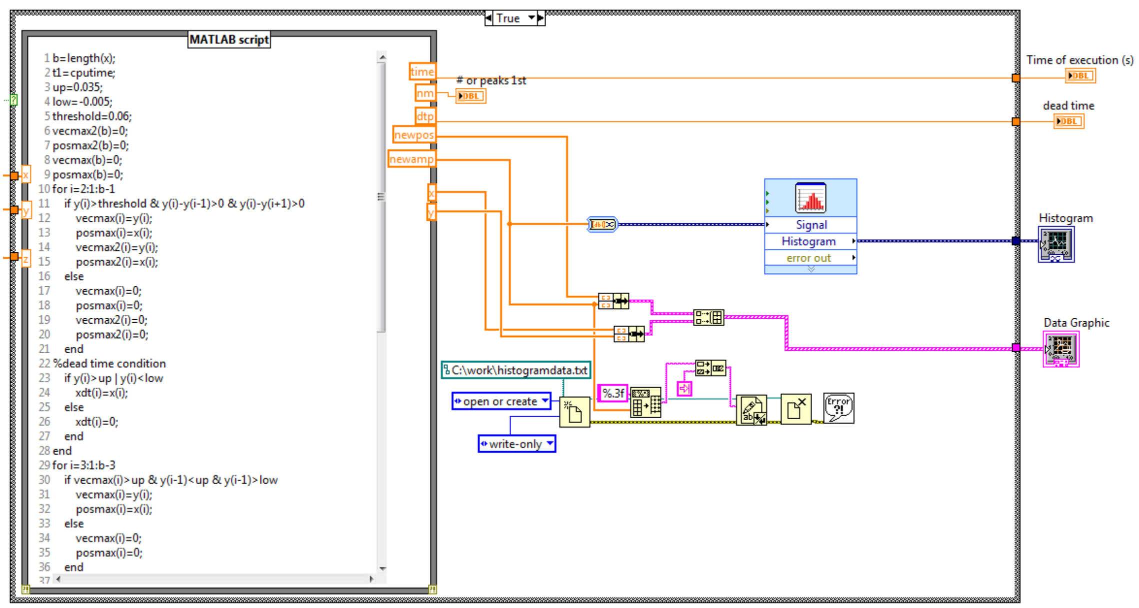

Figure 4.7 Histogram pattern code. True case

The first step to do is to acquire a data file containing a statistically significant number of peaks enough to identify the three typical peaks observed in the decay of the radioactive cobalt isotope (^{57}Co). When the part of the code that we are explaining receives the information about the peaks detected and the data for creating the graph then the variable with the value of the peaks is saved in a file (*histogramdata.txt*) because we will need these values in the second running. Finally the code creates a histogram with the x axis in voltage units. In this stage we also should be able to detect the three peaks commented previously, because the second part of the code will need their position values in voltage units (x_1, x_2).

4.2.1.2. Final histogram (false case)

In order to obtain the total histogram compared with the previous one, the code does some steps (see Figure 4.8).

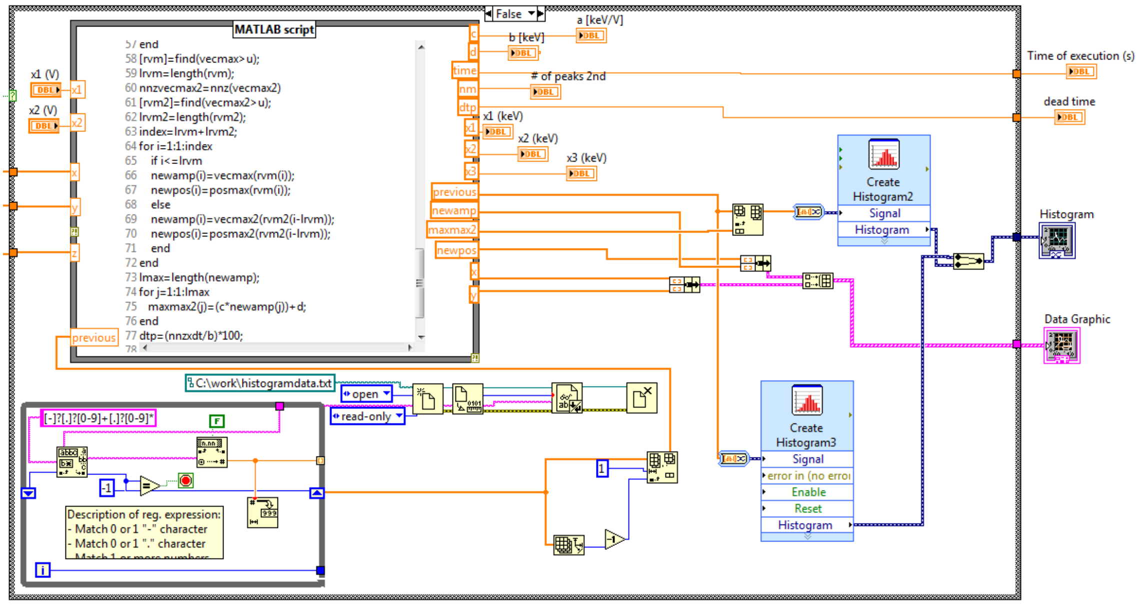

Figure 4.8 Final histogram code. False case

If we have a look over the bottom left part of the code we can see how it opens the previous saved file (*histogramdata.txt*) and gets all the values in order to accomplish two functions: a) create the histogram pattern with the new x axis in energy units; b) to be able to add to this array the new peaks obtained in the second data file. These actions are done by the MatLab script.

First, the code finds the linear equivalent between energy and voltage (Figure 4.9). Then, using the information of the energy window data output, detect the peaks that fulfil the energy window condition. Finally both vector, the ones with the previous maximum and the ones with the previous plus the new peaks, converts their voltage values in energy ones.

In order to calculate the case (a) it is needed x_1, x_2 and the energy of those levels (see Figure 1.5) called in the script as py_1, py_2, and py_3.

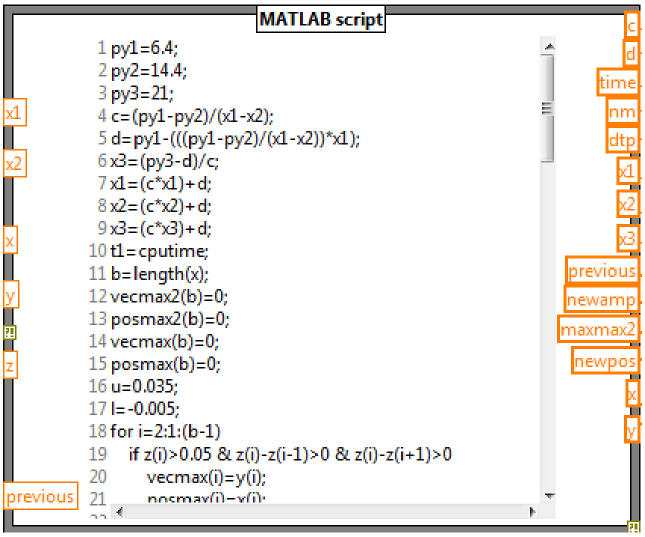

Figure 4.9 MatLab script. Case False

The first part of the code is focused on calculate the linear equivalence between voltage and energy. As it was commented along this section, it is necessary to introduce as input two values (x_1 and x_2) chosen during the first running of the program. Then with x_1, py_1 and x_2, py_2 it is simple to calculate it linear equivalence as:

$$Amplitude(keV) = a \cdot Amplitude(V) + b \qquad \textbf{(5.1)}$$

Finally it is simple to find the solution using x_1, py_1 and x_2, py_2:

$$a = \frac{py_1 - py_2}{x_1 - x_2};\ b = py_1 - \left(\frac{py_1 - py_2}{x_1 - x_2}\right) \cdot x_1 \qquad \textbf{(5.2)}$$

Once we got these values, applying the equation 5.1 with the parameters obtained via 5.2, it is possible to convert the peak’s amplitude value arrays from voltage units to energy units.

In order to obtain the case (b),commented at the beginning of the section 4.2.1 (it means the peaks that contribute to the histogram belonging to the second data file), a new code was created using the information obtained from the output file which data have passed through the energy window (it was explained in subsection 4.2.1.2 *Energy window output data*). The idea of the code (see Annex IV, it contains the MatLab code) is to find the positions where the discriminator indicates that will appear a peak that fulfil the energy window conditions. Once we have this position, the code goes to the amplifier output data vector to find the value of amplitude of this

position. Then as both signals are synchronized, this value is the amplitude of the peak. The final part of the code, applies the conversion between voltage and energy in order to obtain a histogram with its x axis in energy units.

The LV code ends plotting the data file in red, and over their peaks is placed a white circle in order to indicate the peaks taken into account for doing the histogram (Figure 4.10); the code also does two histograms: (a) in yellow the ones who express the initial peaks detected; (b) in red the previous peaks plus the peaks that fulfil the condition of the energy window.

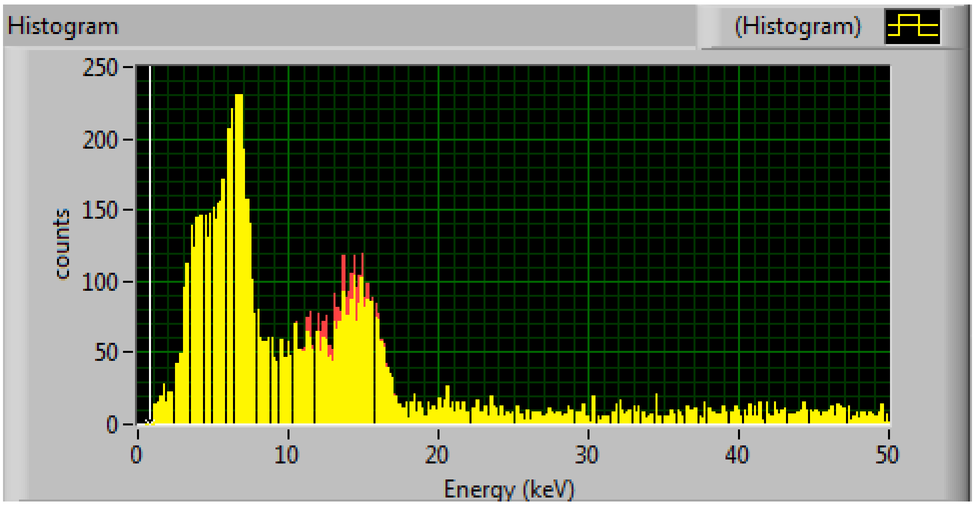

Figure 4.10 Histograms: i) in yellow initial peaks detected; ii) red the same peaks plus the new peaks detected

To decide if the energy window is well placed (remember that it is the main objective of the thesis) we should conclude if the histogram plotted in red have the new values (red over yellow) in the area that corresponds to the peak placed around 14.4 keV. If it does not happen, then we should look which boundary of the energy windows is bad placed. For example, if the peaks in red are placed in energies lower that 14.4 keV the inferior limit of the energy window should be shifted to bigger energies, and then we should obtain another data file and fix the led option *is it the first iteration* switched off in order to analyze if the new position is correct. This procedure should be done until we observe all the peaks in red placed in the area around 14.4 keV. The corresponding steps should be done if the peaks are located over the 14.4 keV.

4.3. Display: Elements and user's manual

The objectives of the display is to offer a tool easy to manage, but with all the information needed.

4.3.1. LabView's Display elements.

Figure 4.11 shows the display at the moment when it is open where we can observe the different elements:

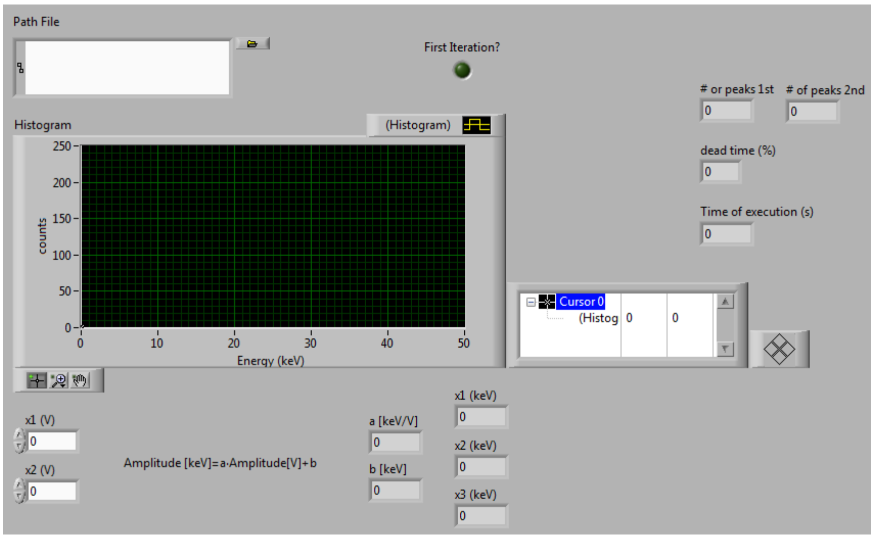

Figure 4.11 LabView display

First of all, it is necessary to distinguish between controls and indicators; controls are in the display in order to introduce any key parameter and indicators are just to show a result.

Working as a control there are some elements as: *path file*, *first iteration?*, x_1 *(V)* and x_2 *(V)*. Instead, as an indicator work: *# of peaks 1st*, *total # of peaks 2nd*, *dead time (%)*, *time of execution (s)*, *a [keV/V]*, *b [keV]*, x_1 *[keV]*, x_2 *[keV]* and x_3 *[keV]*. The function of each element, either control or indicator, will be explained:

Path file: its function is to introduce the data file acquired.

First iteration: this Boolean fix if the data file used is going to be the ones which will work as a histogram pattern or the ones which will be used to confirm where is placed the energy window.

x_1 *(V)*, x_2 *(V)* : After the first time that the program runs, we should identify the three peaks with physical meaning. The first two, are x_1 and x_2. Once we have indentified the peak, we should use the value of the x axis

# of peaks 1st: shows the length of the array containing the peaks detected in the first data file.

# of peaks 2nd: shows the length of the array containing the peaks detected thanks to the energy window discriminator.

dead time (%): shows the percentage of dead time at the detector.

time of execution (s): shows the time that takes MatLab to do the whole data treatment.

a [keV/V]: shows the slope value of the linear equivalence between voltage and amplitude.

b [keV]: shows the constant term of the linear equivalence between voltage and amplitude.

x_1 [keV], *x_2 [keV]*, *x_3 [keV]*: shows the position of the peaks placed in 6.4 keV, 14.4 and 21 respectively.

4.3.2. LabView display user's manual

In order to use properly the code presented during this chapter, it is necessary to carry out three simple steps.

Once we have acquired a statistically significant data file, we set up the display as shows Figure 4.12.

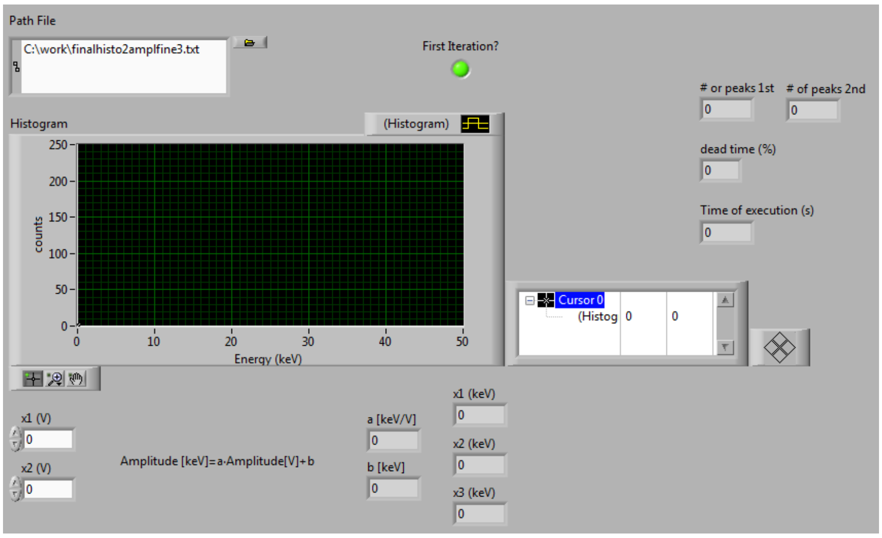

Figure 4.12 Initial display set up

We should just indicate the data file to work with and indicate if it is the first time that the program runs (in order to obtain a histogram pattern and the linear equivalence between voltage and energy).

Once we execute the program, the display obtained is shown in Figure 4.13.

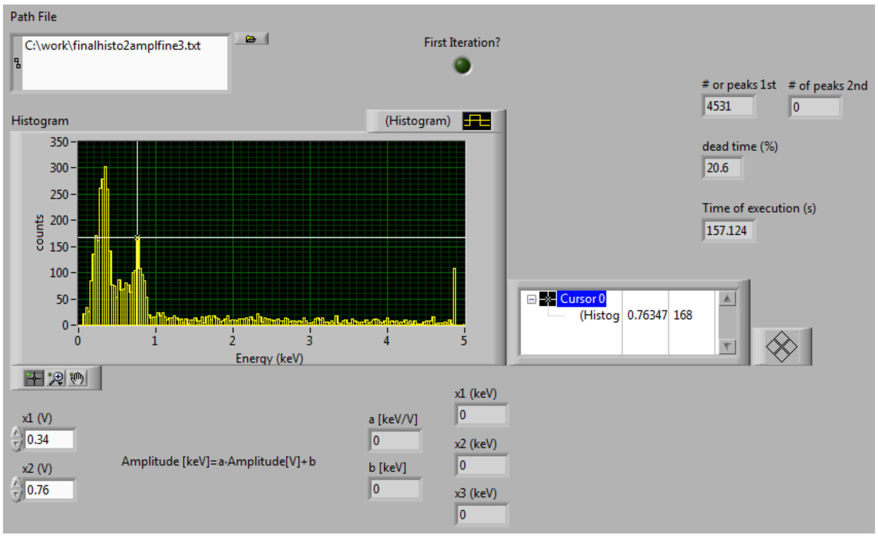

Figure 4.13 The figure shows the intermediate step between the first running and the second

At this point it is essential to observe the histogram obtained because we need to introduce the parameters x_1 *(V)*, x_2 *(V)* with the help of a cursor indicator, in this case the values are 0.35 V and 0.7 V respectively. We obtain the display shown in Figure 4.13 when these two parameters are introduced.

Before the second running we should switch off the Boolean that asks if we are running for the first time or not the code and also to introduce the *path file* of the new data file (which acquires data that have passed through the energy window). The final display is shown in Figure 4.14.

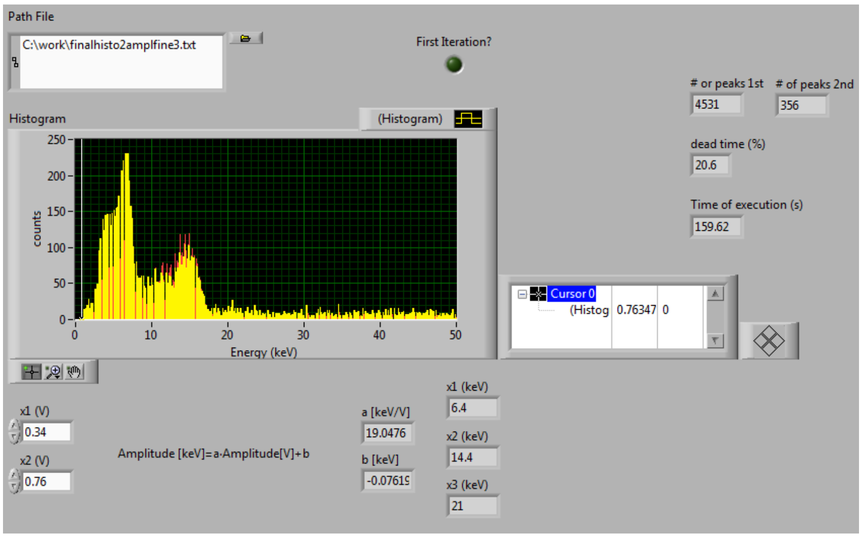

Figure 4.14 Final display

It is possible to observe that the methodology has been chosen to make the use of the code as simple as possible.

Chapter 5

CONCLUSION AND FUTURE WORK

5.1. Conclusion

The main objectives of the projects have been determined since the beginning, and they are to obtain and design a Photon Height Analyzer displayed as a histogram (or spectrum) of the radioactive source and also to obtain information about the dead time of the detector considering that we were involved in a low cost project.

In Chapter 2 we were conscious that, although our set up using an external divisor probe (instead of a coaxial cable) will improve the data acquired, the digital oscilloscope analogue to digital converser will increase the time of data acquisition of our Photon Height Analyzer.

There exists the inconvenient caused by this time increase of the data acquisition (around fifteen minutes, plus 45 minutes that runs the code); but it is permitted because, we have replaced a commercial software and acquisition system card that cost around 4000 € around teen years ago by our system that has cost 200 €. In addition the system will be only used twice or three times every year.

It was determined that the amplifier is also a differentiator thanks to the image obtained of the Bode diagram.

5.2. Future work

There are some ideas that could improve this project and could be done as a future work, but they are out of this project possibilities.

First of all, could be a good idea to build an adapter between the amplifier (and energy window) and the external divisor probe in order to ensure that during the twenty minutes that takes the oscilloscope to acquire data, the connexion will be the best.

Secondly, and example of how to create a dynamic data exchange is shown in Annex VI just in case the manufacturer decide to send us a software that can allow us to work in streaming mode (as they promised us.

Third, the possibility to change the hardware of the digital oscilloscope in order to permit to obtain data faster could also be studied. It would be necessary a faster analogue to digital converter and also a bigger internal memory for the oscilloscope.

Finally it could be done a complete study of the LabView and MatLab code in order to check some options for reducing the time that the program is running.

REFERENCES

[1] Mössbauer, R. L., Z. Physik 151, 124 (1958); Naturwissenschaften 45, 538 (1958); Z. Naturforsch 14a, 211 (1959).

[2] Morris, R.V. et al. “Mössbauer mineralogy of rock, soil, and dust at Gusev Crater, Mars: Spirit’s journey through weakly altered olivine basalt on the Plains and pervasively altered basalt in the Columbia Hills”, *NASA publication, revised for Journal of Geophysical Research Planets*, October, 2005

[3] Heiman, N., Hester, R. K., and Weeks, S. P., “Mössbauer-Effect”, “Measurement of the Relaxation Time of Ultrasonic Vibrations in Fe Foils”; *Phys. Rev.* B 8, 3145–3150 (1973).

[4] Gummer, A.W., Smolders, J.W.T. and Klinke, R., “Basilar membrane motion in the pigeon measured with the Mössbauer technique”, *Hearing Research*, Volume 29, Issue 1, 1987, Pages 63-92, November,1987.

[5] Pound, R.V. and Rebka Jr., G.V., *Phys. Rev. Letters* 4, 337 (1960).

[6] Adapted from Dyar, M.D., Agresti, D. G., Schaefer, M. W., Grant, C. A. And Sklute, E.C., Annu. *Rev. Earth Planet*. Sci., 2006, 34, 83, (2006).

[7] Dickson, P.E. and Berry, F.J., “Principles of Mössbauer spectroscopy”, Chapter 1 in *Mössbauer Spectroscopy*, Cambridge University Press, Cambridge (1986).

[8] Doppler, C., “Über das farbige Licht der Doppelsterne und einiger anderer Gestirne des Himmels”, *Abhandlungen der k. böhm. Gessellschaft der Wissenschaften (V. Folge, Bd. 2, S. 465-482)*, (1842).

[9] Compton, A. H., “A quantum theory of the Scattering of X-rays by Light Elements”, *Phys. Rev. 21, 483-502, (1923)*.

[10] Cramberra amplifiers catalogue, http://www.canberra.com/pdf/Products/Model-2022-SS-M3833.pdf

[11] Spectroscopy amplifier Model 2022, Operator’s Manual

[12] Planck, M., "On the Law of Distribution of Energy in the Normal Spectrum". *Annalen der Physik*, vol. 4, p. 553 ff (1901)

Annex I

USB OSCILLOSCOPES LIST

This is a list with all the different options to choose the USB oscilloscope. As it was commented in section 3.1.1, the feature that most affect to the prize is the n (number of bits), followed by the SR (sampling rate).

Table A1.1 Oscilloscopes list

Model	***Channel***	***SR (Msamp/sec)***	***n***	***Cost ($US)***
PropScope	2	25	10	250
PicoScope 2204	2	1 Channel 100 2 Channel 50	8	354
Gao 2090	2	100	8	259
CS320A	2	100	12	1200
TiePie HS3	2	10	12	1100

The decision was taken considering that the key feature was the bit number, and that the project needed an oscilloscope of 10 bits. Due to this to affirmations, it was easy to choose PropScope as a good tool to carry out the project.

Annex II

CIRCUIT ANALYSIS

The objective of this annex is to show in detail a theoretically study of the different wires that can be chosen to work in the laboratory. The idea is to show theoretically how the system works in order to compare with the real data;

A2.1 Circuit wired with coaxial cable

The objective of a circuit's analysis is to find the transfer's function of the system and to analyze how the errors (introduced by the impedances) in the measured data depend on the frequency or amplitude. The figure below shows the circuit's scheme with the different passives elements as capacitances and resistances.

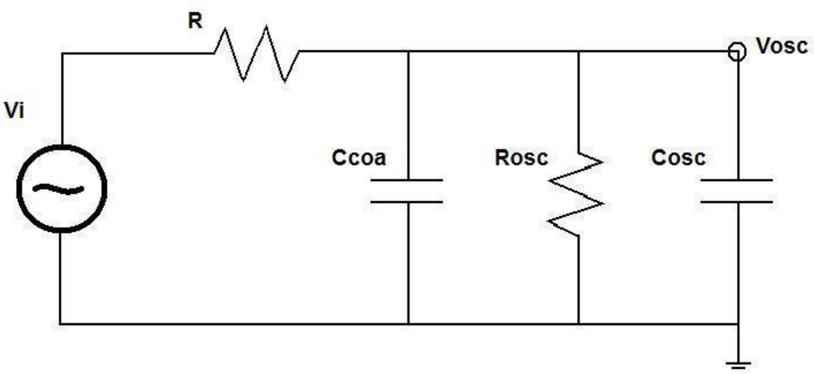

Figure A2.1 Circuit's scheme wired with coaxial cable; Vi is the output signal, R is the amplifier's output resistance, Ccoa is the capacitance of the coaxial cable, Rosc and Cosc are referred to the oscilloscope's input

To solve easily the circuit, it is necessary to build an equivalent circuit. It is possible to calculate the equivalent impedance of two capacitances in parallel. The equivalent circuit works as a voltage divisor. If we take into account that the input resistance is ten thousands time bigger than the output resistance of the amplifier then it is clear than the equivalent resistance for the equivalent circuit is the output resistance of the amplifier.

$$C_{eq} = C_{coa}||\mathrm{C_{osc}} = \mathrm{C_{coa}} + \mathrm{C_{osc}} \quad \textbf{(A2.1)}$$

$$\mathrm{R_{eq}} \overset{\mathrm{R \ll R_{osc}}}{\cong} \mathrm{R} \quad \textbf{(A2.2)}$$

Then the equivalent circuit (see Figure A2.2) is formed by a resistance in series with a capacitance; that is the classical configuration of a low pass filter.

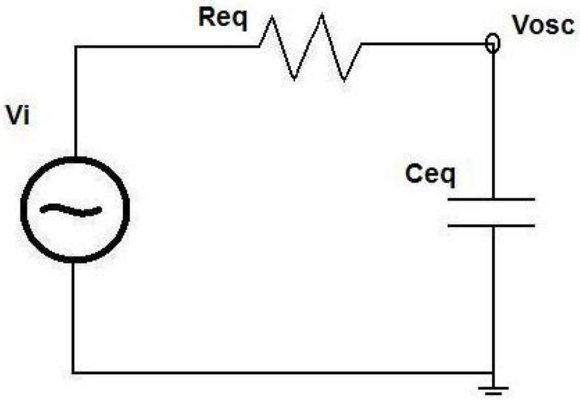

Figure A2.2 Equivalent circuit's scheme using coaxial cable

This is a basic circuit to solve:

$$V_{osc} = V_i - R_{eq} \cdot I \qquad \textbf{(A2.3)}$$

$$V_{osc} = C_{eq} \cdot I \qquad \textbf{(A2.4)}$$

Isolating the intensity in equation A2.4, and substituting in equation A2.3, it is obtained:

$$I = \frac{V_{osc}}{C_{eq}} \rightarrow V_{osc} = V_i - R_{eq} \cdot \frac{V_{osc}}{C_{eq}} \qquad \textbf{(A2.5)}$$

Reordering equation A2.5, it is possible to obtain the transfer's function of the circuit:

$$V_{osc}\left(1 + \frac{R_{eq}}{Z_{eq}}\right) = V_i \rightarrow \frac{V_{osc}}{V_i} = \frac{1}{1+\frac{R_{eq}}{C_{eq}}} \rightarrow \frac{V_{osc}}{V_i} = \frac{C_{eq}}{C_{eq}+R_{eq}} \overset{(1.2)}{\triangleq} \frac{C_{eq}}{C_{eq}+R} \qquad \textbf{(A2.6)}$$

In order to express the transfer's function in the complex frequency domain, it is necessary to express the impedance in terms of frequency (because resistance does not depend on frequency), then:

$$Z_{capacitance} = \frac{1}{sC}; \;\; s = jw \qquad \textbf{(A2.7)}$$

Introducing (A2.7) in (A2.6),

$$T(s) = \frac{V_{osc}}{V_i} = \frac{1/_{sC_{eq}}}{1/_{sC_{eq}}+R} = \frac{1}{sC_{eq}} \cdot \frac{\frac{1}{sC_{eq}}}{\frac{1+sRC_{eq}}{sC_{eq}}} = \frac{1}{1+sRC_{eq}} \quad \textbf{(A2.8)}$$

Equation A2.8 shows that the function's transfer in the complex frequency domain depends on frequency (represented as s); the circuit works as a low pass filter. To find the cut frequency of the low-pass filter it is necessary to find the zero of the transfer function's divisor.

$$|1 + sRC_{eq}| = 0 \rightarrow s = \frac{1}{RC_{eq}} \overset{(A2.7)}{\rightarrow} w_{cut} = \frac{1}{RC_{eq}} \quad \textbf{(A2.9)}$$

Using,

$$w = 2\pi f \quad \textbf{(A2.10)}$$

Finally,

$$f_{cut}^{coa} = \frac{1}{2\pi RC_{eq}} = 15{,}9MHz \quad \textbf{(A2.11)}$$

To determine the transfer's function at time domain it is necessary to do the reverse Laplace transform; the expression A2.8 could be rewritten as:

$$T(s) = \frac{1}{RC_{eq}} \cdot \frac{1}{s+\frac{1}{C_{eq}R}} = \frac{1}{RC_{eq}} \cdot \frac{1}{s-\left(\frac{-1}{C_{eq}R}\right)} \quad \textbf{(A2.12)}$$

It is simple to do the reverse Laplace's transform using the two following properties:

$$\mathcal{L}^{-1}[a \cdot F(s)] = a \cdot \mathcal{L}^{-1}[F(s)] \quad \textbf{(A2.13)}$$

$$\mathcal{L}^{-1}\left[\frac{1}{s-\gamma}\right] = e^{\gamma t} \quad \textbf{(A2.14)}$$

Therefore, the transfer's function expressed at time domain is:

$$\frac{V_{osc}}{V_i} = \frac{1}{RC_{eq}} e^{-\frac{1}{RC_{eq}}t} \quad \textbf{(A2.15)}$$

This equation shows that for a peak observed, the transfer function applied in it is an exponential decay with a discharge time constant:

$$\tau = RC_{eq} = 100 \cdot 100 \cdot 10^{-12} = 10ns \quad \textbf{(A2.16)}$$

It is possible to see in equation A2.8 that the function's transfer is a function of frequency; as it has been commented before, the circuit works as a low pass filter, and at this point it is possible to calculate the cut's frequency,

$$\left|1 + sRC_{eq}\right| = 0 \ \rightarrow s = \frac{1}{RC_{eq}} \overset{(A2.7)}{\rightarrow} w_{cut} = \frac{1}{RC_{eq}} \quad \textbf{(A2.17)}$$

Using,

$$w = 2\pi f \quad \textbf{(A2.18)}$$

The expression for calculate the cut's frequency is:

$$f_{cut}^{coa} = \frac{1}{2\pi RC_{eq}} \quad \textbf{(A2.19)}$$

It means that for frequency equal o higher to the cut's frequency, the data will be modified as (using equation A2.8):

$$E_{rel} = \left|\frac{V_i - V_{osc}}{V_i}\right| \times 100 = \left|\frac{V_i - |T(w)V_i|}{V_i}\right| \times 100 \quad \textbf{(A2.20)}$$

The voltage measured in the oscilloscope can be expressed as the input voltage multiplied by the transfer function:

$$v_{osc} = |T(jw)| \cdot v_i \quad \textbf{(A2.21)}$$

It is necessary to calculate the module of the transfer function because it is a complex number, with both parts, real and complex.

The transfer function (equation A2.8) has its complex element in the denominator; in consequence it is going to be multiplied in the numerator and in the divisor also by its conjugate complex. Then will be possible to separate the real part form the complex one (as it is shown in the equation below):

$$T(jw) \overset{(A2.8)}{=} \frac{1}{1+jRCw} \cdot \frac{(1-jRCw)}{(1-jRCw)} \quad \textbf{(A2.22)}$$

Then, at this point it is possible to separate the real part and the complex ones:

$$T(jw) = \frac{1}{1+R^2C^2w^2} - j \cdot \frac{RCw}{1+R^2C^2w^2} \quad \textbf{(A2.23)}$$

Therefore the module of the function transfer is:

$$|T(jw)| = \sqrt{\left(\frac{1}{1+R^2C^2w^2}\right)^2 + \frac{R^2C^2w^2}{(1+R^2C^2w^2)^2}} = \sqrt{\frac{1+R^2C^2w^2}{(1+R^2C^2w^2)^2}} \quad \textbf{(A2.24)}$$

And finally:

$$|T(jw)| = \sqrt{\frac{1}{1+R^2C^2w^2}} \quad \textbf{(A2.25)}$$

Going back to equation A2.20, equation below shows how a low pass filter works, and then depending on the frequency the signal has a different attenuation.

$$E_{rel} = \left|\frac{v_i \cdot \left(1 - \sqrt{\frac{1}{1+R^2C^2w^2}}\right)}{v_i}\right| \times 100 = \left|\frac{1 - \sqrt{\frac{1}{1+R^2C^2w^2}}}{1}\right| \times 100 \quad \textbf{(A2.23)}$$

A2.2 Circuit wired with an external divisor probe

In this section, the external divisor probe (EDP) replaces the coaxial cable. The EDP includes a coaxial cable and a RC front net with an adjustable capacitance; it offers a higher input resistance and lower capacity in parallel than the oscilloscope alone (figure A2.3).

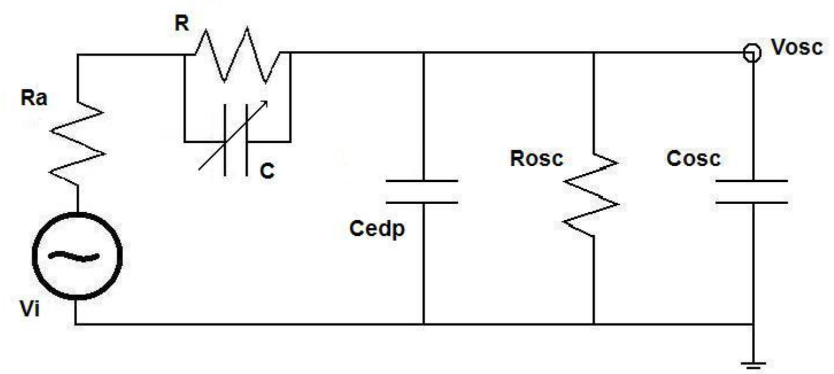

Figure A2.3 Circuit's scheme wired with EDP; Vi is the output signal, Ra is the amplifier's output resistance, R is the resistance of the RC net, C is the adjustable capacitance, Cedp is the capacitance of the coaxial cable, Rosc and Cosc are referred to the oscilloscope

The circuit will be separated in two parts; the first study will consist in to find an equivalent circuit of the elements that do not belong to the amplifier.
In consequence, it is necessary to calculate the impedance of a capacitance and a resistance in parallel:

$$\frac{1}{Z_1} = \frac{1}{R} + \frac{1}{1/_{sC}} = \frac{1+sRC}{R} \;\rightarrow\; Z_1 = \frac{R}{1+sRC} \tag{A2.24}$$

And to calculate the impedance of two capacitances in parallel, both in parallel with a resistance:

$$C_{eq} = C_{edp}||\mathrm{C_{osc}} = \mathrm{C_{edp}} + \mathrm{C_{osc}} \tag{A2.25}$$

$$\frac{1}{Z_2} = \frac{1}{R_{osc}} + \frac{1}{1/_{sC_{eq}}} = \frac{1+sR_{osc}C_{eq}}{R_{osc}} \;\rightarrow\; Z_2 = \frac{R_{osc}}{1+sR_{osc}C_{eq}} \tag{A2.26}$$

Then it is possible to represent the circuit as figure A2.4:

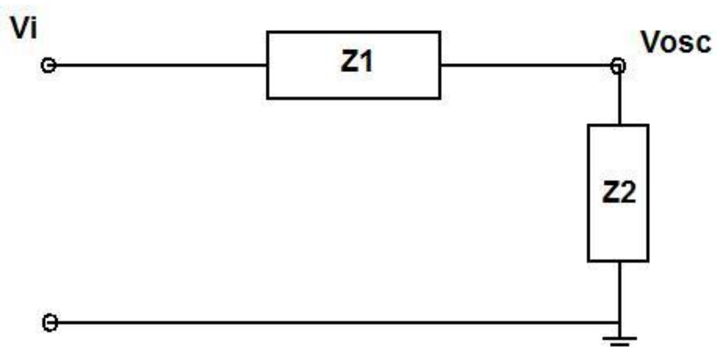

Figure A2.4 Equivalent circuit's scheme with impedance

At that point, it is possible to adapt the expression A2.6 substituting R by Z_1 and Z_{eq} by Z_2, obtaining directly:

$$\frac{V_{osc}}{V_i} = \frac{Z_2}{Z_2+Z_1} \tag{A2.27}$$

Writing equation A2.27 in the frequency domain:

$$T(s) = \frac{\frac{R_{osc}}{1+sR_{osc}C_{eq}}}{\frac{R_{osc}}{1+sR_{osc}C_{eq}}+\frac{R}{1+sRC}} = \frac{R_{osc}}{R_{osc}+R\cdot\frac{1+sR_{osc}C_{eq}}{1+sRC}} \tag{A2.28}$$

If,

$$R_{osc}C_{eq} = RC \tag{A2.29}$$

Then the EDP is compensated; it is clear that C must be adjustable because each oscilloscope has different resistance and capacitance.

In the PropScope case, the adjustable C is:

$$C = \frac{R_{osc}C_{eq}}{R} \cong \frac{C_{eq}}{10} \quad \textbf{(A2.30)}$$

Returning to equation A2.28, and assuming A2.29, the transfer function resulting is:

$$T(s) = \frac{R_{osc}}{R_{osc}+R} \cong \frac{1}{10} \quad \textbf{(A2.31)}$$

This result, as was expected, means that this part of the circuit does not affect to the measure data in frequency, but data are attenuated by factor 0,1in amplitude as is seen in equation A2.32 where the reverse Laplace transform has been applied.

$$V_{osc} = V_i \cdot \frac{R_{osc}}{R_{osc}+R} = \frac{V_i}{10} \quad \textbf{(A2.32)}$$

Using the admittance it is possible to find the values equivalent to the capacitance and resistance. In order to work with admittance, firs it is necessary to calculate the total impedance:

$$Z_{total} = Z_1 + Z_2 = \frac{R}{1+sRC} + \frac{R_{osc}}{1+sR_{osc}C_{eq}} \overset{(A2.30)}{\cong} \frac{R}{1+\frac{sRR_{osc}C_{eq}}{R}} + \frac{R_{osc}}{1+sR_{osc}C_{eq}} \quad \textbf{(A2.33)}$$

$$Z_{total} = \frac{R_{osc}+R}{1+sR_{osc}C_{eq}} \overset{(A2.7)}{\cong} \frac{R_{osc}+R}{1+jwR_{osc}C_{eq}} \quad \textbf{(A2.34)}$$

And the admittance is:

$$Y = \frac{1}{Z_{total}} = \frac{1+jwR_{osc}C_{eq}}{R_{osc}+R} = \frac{1}{R_{osc}+R} + jwC_{eq} \cdot \frac{R_{osc}}{R_{osc}+R} \quad \textbf{(A2.35)}$$

Therefore the system acts as an equivalent resistance and an equivalent in parallel with the following values:

$$R_{eq} = R_{osc} + R \cong 10M\Omega \quad \textbf{(A2.36)}$$

$$C_{sys} = C_{eq} \cdot \frac{R_{osc}}{R_{osc}+R} = \frac{C_{eq}}{10} \overset{(A2.2)}{\cong} \frac{\mathrm{C_{edp}}+\mathrm{C_{osc}}}{10} = \frac{(20+80)pF}{10} = 10pF \quad \textbf{(A2.37)}$$

In consequence, the equivalent circuit is (Figure A2.5):

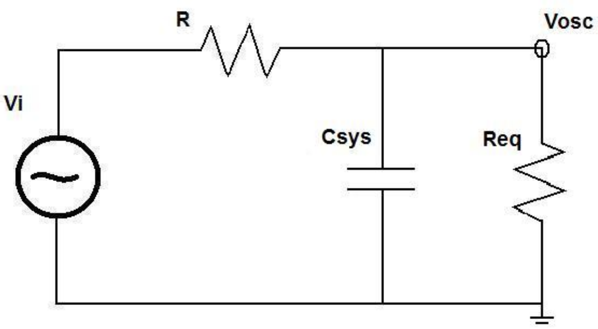

Figure A2.5 Scheme of equivalent circuit wired with EDP

As it was commented at the beginning of the section A2.2, the equivalent system has a bigger input resistance, and a smaller capacitance than the case of section A2.1.

The purpose is to demonstrate why this circuit is better option; the first step is to calculate the equivalent resistance (as was done in section A2.1):

$$R_{sys} = R||\mathrm{R_{eq}} \rightarrow \frac{1}{\mathrm{R_{sys}}} = \frac{1}{\mathrm{R}} + \frac{1}{\mathrm{R_{eq}}} \overset{\mathrm{R} \ll \mathrm{R_{eq}}}{\cong} \frac{\mathrm{R_{eq}}}{\mathrm{R} \cdot \mathrm{R_{eq}}} = \frac{1}{\mathrm{R}} \rightarrow \mathrm{R_{sys}} = \mathrm{R} \quad \textbf{(A2.38)}$$

This circuit of figure A2.6 is analogous to the circuit shown in Figure A2.2, although with different parameters. In consequence it is going to show just the highlights of the process.

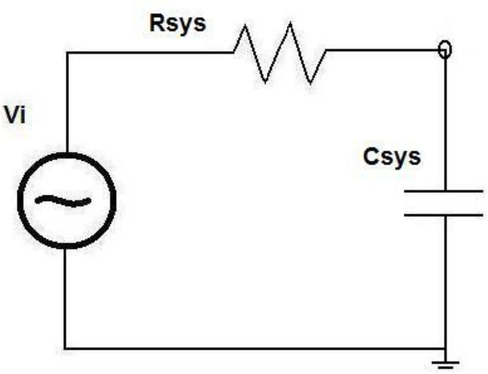

Figure A2.6 Equivalent circuit's scheme using coaxial cable

Accordingly the transfer function is (A2.8):

$$T(s) = \frac{1}{1 + sC_{sys}R} \quad \textbf{(A2.39)}$$

It is dependent on frequency but in that case (as it is in A2.19) the cut frequency is:

$$f_{cut}^{EDP} = \frac{1}{2\pi RC_{sys}} = 10 \cdot f_{cut}^{coa} \qquad \textbf{(A2.40)}$$

It is a great improvement, because just changing the wire type; the system is able to obtain data with a frequency ten times bigger without being modified.

Finally, as was explained in the section A2.1, the peaks with equal or higher frequencies than the cut frequency, will be modified in amplitude as (analogous to equation A2.23):

$$E_{rel} = \left|\frac{V_i - V_{osc}}{V_i}\right| \times 100 = \left|\frac{1 - \frac{1}{\sqrt{1+R^2C_{eq}^2w^2}}}{1}\right| \times 100 \qquad \textbf{(A2.40)}$$

With the study done above, we can conclude that the use of the EDP instead of the coaxial cable will suppose an improvement of our data measuring system.

Annex III

COMPARING DATA OBTAINED USING COAXIAL CABLE AND EXTERNAL DIVISOR PROBE

In Chapter 2, section 2.3, were analyzed graphically two options to wire the amplifier and the USB oscilloscope: coaxial cable (CC) and external divisor probe (EDP).

In section 2.4 was done the same study for the whole system, analyzing both circuits with their different elements.

In both cases were clear that the introduction of an EDP instead of a CC will improve the quality of the measures.

In consequence this annex pretends to express these improvements on data, observing the effects on the final result, the amplitude histogram.

The figure below shows both histograms:

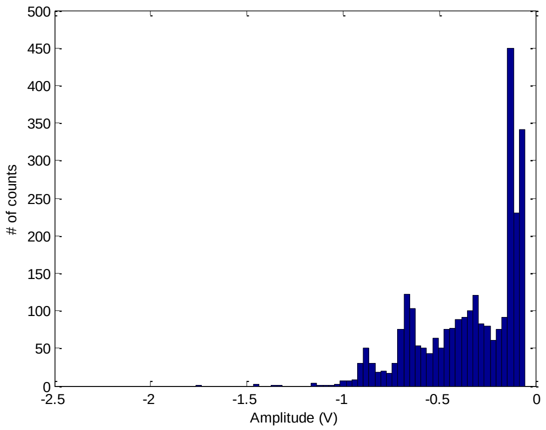

Figure A3.1 Measures done with coaxial cable

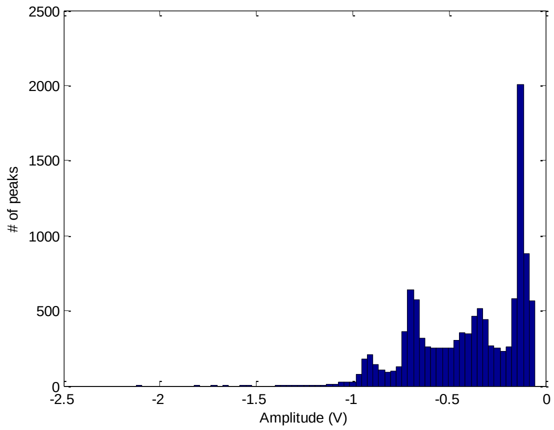

Figure A3.2 Measures done with EDP

Just observing both images, it is clear that the histogram of Figure A.3.2 has its maximums values more concentrated than Figure A.3.1, where they are more scattered.

Before to analyze both histograms, it is interesting to compare them with a previous work to be able to give an opinion depending on what we are observing.

Figure A.3.3 shows the data obtained in the laboratory with the previous acquisition card.

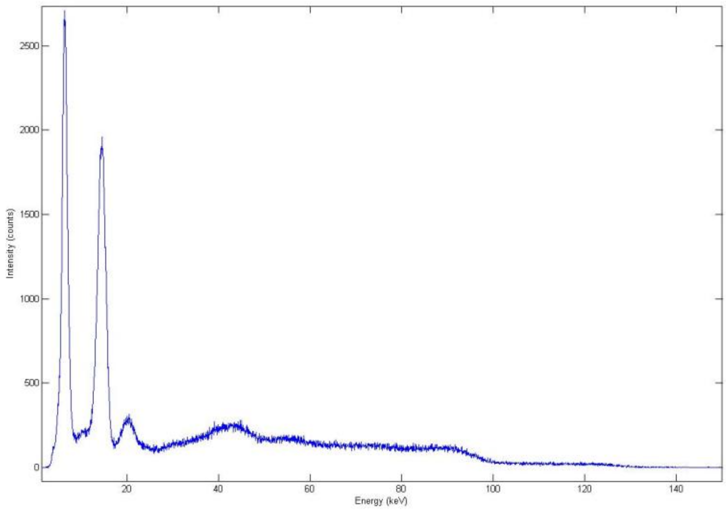

Figure A3.3 Laboratory data histogram (spectrum)

The figure A.3.3 has it x axes in energy units; it is possible to convert the data shown in Figure A.3.2 to energy just using theoretical results. The idea is identify a maximum in the histogram with its energy very well known.

That is why the histogram A.3.2 is more clear than the histogram A.3.1 where is more difficult to be able to determine a maximum. This is the reason why from here in advance, it is just commented histogram A.3.2.

Comparing histograms A.3.2 and Figure A.3.3 it is possible comment that:

- The maximum located around 0.35 V (Figure A.3.2) must correspond to the peak located around 6.4 keV in Figure A.3.3.
- The maximum located around 0.7 V (Figure A.3.2) must correspond to the peak located around 14.4 keV in Figure A.3.3.
- The maximum located around 0.9 V (Figure A.3.2) must correspond to the peak located around 21 keV in Figure A.3.3.

To ensure that the identification has been well done it is necessary to remember that the amplifier has a lineal gain (it was commented in section 2.4). In consequence it is necessary to select two points that must correspond to the peaks located in 6.4 and 14.4 keV respectively; then it is possible to do a lineal regression in order to obtain the straight line that contains both points in the histogram.

The energy value of the third peak shown in figure A.3.3 is 21 keV; then substituting this value in the straight line and isolating the value of the x axes it is possible to find where the third maximum must be located in the histogram. If both coincide then the supposition done with the two initial peaks are correct. If was necessary, it is possible to make the whole conversion between amplitude and energy on the histogram.

The other feature that should be commented in this annex is the number of minimum obtained.

In section 2.3 was commented that both circuits were working as a low pass filter; although the circuit wired with EDP had a cut frequency ten times higher. In consequence the faster peaks cannot be obtained in a circuit with the coaxial cable, concretely the peaks with frequency higher than 16 MHz (cut frequency of circuit wired with CC) and lower that 20 MHz (bandwidth of the oscilloscope).

The table A3.1 shows the ratio between points obtained and minimums detected for both circuits, wired with EDP and CC.

Table A3.1 Ratio between points analyzed and minimum detected.

	# of points	*# of peaks*	*Ratio (%)*
CC	1,329.152	2.751	0,20
EDP	1,348.608	11.487	0,85

As was predicted by the theory, the ratio between the number of points acquired ant the peaks detected is more than four time greater for the circuit wired with the external divisor probe.

The main consequence of this observation is that changing the cable that wires the circuit, then the acquisition time can be reduced four times maintaining the statistics.

This is a great improvement; more if it is taken into account the limitation that the oscilloscope imposes over the acquisition time.

Annex IV

MATLAB CODE

Code created to obtain all the peaks from the amplifier unipolar output data without overlapped peaks

```
clear all
a=load('finalhisto2amplfine3.txt');
b=length(a(:,1));
a(:,1)=(1:b);
x=a(:,1);
y=a(:,3);
z=a(:,4);
threshold=0.06;
u=0.035;
l=-0.005;
vecmax2(b)=0;
posmax2(b)=0;
vecmax(b)=0;
posmax(b)=0;
for i=2:1:b-2
    if y(i)>threshold & y(i)-y(i-1)>0 & y(i)-y(i+1)>0
        vecmax(i)=y(i);
        posmax(i)=x(i);
        vecmax2(i)=y(i);
        posmax2(i)=x(i);
    else
        vecmax(i)=0;
        posmax(i)=0;
        vecmax2(i)=0;
        posmax2(i)=0;
    end
    if y(i)>u | y(i)<l
        xdt(i)=x(i);
    else
        xdt(i)=0;
    end
end
nnzxdt=nnz(xdt);
for i=3:1:b-3
    if vecmax(i)>u & y(i-1)<u & y(i-1)>l
        vecmax(i)=y(i);
        posmax(i)=x(i);
    else
        vecmax(i)=0;
        posmax(i)=0;
    end
    if vecmax2(i)>u & y(i-2)<u & y(i-2)>l
        vecmax2(i)=y(i);
        posmax2(i)=x(i);
    else
        vecmax2(i)=0;
        posmax2(i)=0;
```

```
    end
end
nnzvecmax=nnz(vecmax)
[rvm]=find(vecmax>u);
lrvm=length(rvm);
nnzvecmax2=nnz(vecmax2)
[rvm2]=find(vecmax2>u);
lrvm2=length(rvm2);
index=lrvm+lrvm2
for i=1:1:index
    if i<=lrvm
    newamp(i)=vecmax(rvm(i));
    newpos(i)=posmax(rvm(i));
    else
    newamp(i)=vecmax2(rvm2(i-lrvm));
    newpos(i)=posmax2(rvm2(i-lrvm));
    end
end
dtpercentage=(nnzxdt/b)*100
amplitude=[0:0.05:5.5];
hist(newamp,amplitude);
figure;plot(x,y,'b-',newpos,newamp,'ro')
```

Code created to detect all the peaks that fulfil the energy window condition without peaks overlapped:

```
clear all
a=load('dani.txt');
b=length(a(:,1));
a(:,1)=(1:b);
x=a(1:(b/16),1);
y=a(1:(b/16),3);
z=a(1:(b/16),4);
bbb=b/16;
vecmax2(b)=0;
posmax2(b)=0;
vecmax(b)=0;
posmax(b)=0;
u=0.035;
l=-0.005;
for i=2:1:(bbb-1)
    if z(i)>0.05 & z(i)-z(i-1)>0 & z(i)-z(i+1)>0
        vecmax(i)=y(i);
        posmax(i)=x(i);
        vecmax2(i)=y(i);
        posmax2(i)=x(i);
    else
        vecmax(i)=0;
        posmax(i)=0;
        vecmax2(i)=0;
        posmax2(i)=0;
    end
end
for i=3:1:b-3
    if vecmax(i)>u & y(i-1)<u & y(i-1)>l
        vecmax(i)=y(i);
        posmax(i)=x(i);
```

```
    else
        vecmax(i)=0;
        posmax(i)=0;
    end
    if vecmax2(i)>u & y(i-2)<u & y(i-2)>l
        vecmax2(i)=y(i);
        posmax2(i)=x(i);
    else
        vecmax2(i)=0;
        posmax2(i)=0;
    end
end
[rvm]=find(vecmax>u);
lrvm=length(rvm);
nnzvecmax2=nnz(vecmax2);
[rvm2]=find(vecmax2>u);
lrvm2=length(rvm2);
index=lrvm+lrvm2;
for i=1:1:index
    if i<=lrvm
    newamp(i)=vecmax(rvm(i));
    newpos(i)=posmax(rvm(i));
    else
    newamp(i)=vecmax2(rvm2(i-lrvm));
    newpos(i)=posmax2(rvm2(i-lrvm));
    end
end
amplitude=[0:0.05:5.5];
hist(newamp,amplitude);
figure;plot(x,y,'b-',x,z,'g-',newpos,newamp,'ro')
```

Annex V

ALTERNATIVE PEAK DETECTION AND HISTOGRAM

Since the beginning of the project we thought that could be possible to obtain the spectrum of the radioactive sample using the peak that has a near-Gaussian shape instead of the peak that is similar to a Dirac's delta. We also thought that the information about dead time could be obtained first, detecting all the peaks, and then impose an overlapping condition to remove the peaks overlapped.

Finally we realize that the most reliable way of work should be the ones presented in Chapter 3.

As the final histogram is very similar to the histogram obtained in Chapter 3, then here will be presented the alternative work.

Some of the previous information necessary to follow this explanation is offered in Chapter 3, since the beginning until section 3.2.2 *Peaks detection*.

I would like to explain that at the first stage of numerical treatment the idea was to simulate the signal observed in the analogue oscilloscope; this MatLab code was done before the analysis that will be shown later (section A.1) was finished, at those moments we had not taken the decision of which USB oscilloscope to buy yet; In consequence the first approach to the data was to create a MatLab code, which recreates the signal observed in an analogue oscilloscope. The oscilloscope signal's recreation could allow starting to check the MatLab code with a kind of simulated real data. Once the oscilloscope was bought and it was in the laboratory, the following stage was to determinate how it works i.e.: sampling frequency (f_s), data transfers, clipped effect, etc explained in Chapter 3.

A3.1. Signal simulation

Once the signal was observed, one of the most plausible options was to use the form of the Planck's Law **[12]** because its shape was asymmetrical and similar to the near-Gaussian curve used in the amplifier. The parameters which determine the shape where modified randomly because the objective was to recreate all kind of peaks; figure A5.1 shows the simulation obtained.

It is possible to see that there are peaks with different amplitudes, widths and some of them are overlapped (as the original signal).

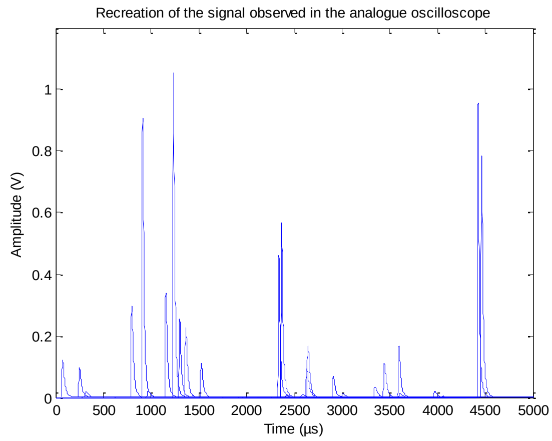

Figure A5.1 Recreation of the signal observed in the analogue oscilloscope

Just at the time that the recreation was finished, the USB oscilloscope arrived to the laboratory; in consequence there was no reason to continue working on this idea instead to work with original data from the Mössbauer experiment.

A3.2. MatLab code

A3.2.1. Peaks detection

The signal shows peaks in both amplitude zones, positive and negative created by the differentiator of the amplifier. We are going to work with the peak with near-Gaussian shape, in consequence the signal can be modified in the positive area in order to make easier the data treatment (see Figure A5.2).

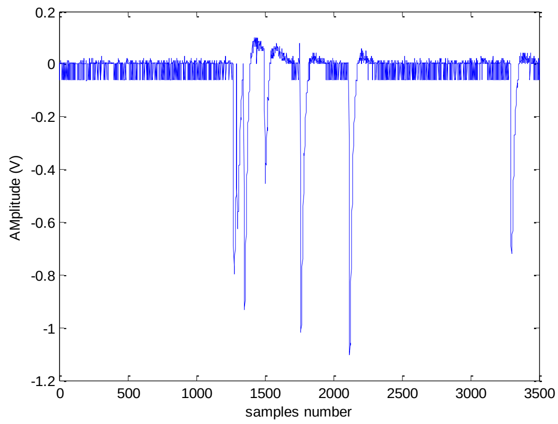

Figure A5.2 Signal without values greater than 65 mV (excepting peaks)

To work just with the lower part of the signal does not mean that the data is being altered; to make it clear, every time that the signal would be shown it is going to be use the full original signal and will be possible to check visually that the peak are perfectly detected in amplitude and time.

When the signal is amplified around the zero amplitude value, it is possible to realize that the signal remains swinging around the zero with a minimum value of 65 mV; this allows to determinate perfectly the minimum value acceptable for a peak. In other words, it is like creating a filter for amplitudes smaller than 65 mV.

The feature commented in the previous paragraph will make easier the data treatment. It must be commented that this feature does not happens with the coaxial cable, where the noise values were much more scattered.

Then to characterize basically the signal, there exists two different behaviours: (i) when there is not emission, the signal remain around zero with a minimum value of (-0.065 *V*) very well determinate (see figure A5.3); (ii) when there is a peak the values are all of them getting bigger (absolute value). As the objective is to determine the peaks due to emission process, the region (i) allows to determine properly the minimum value accepted to consider a minimum; Then using a 'for' loop it is very simple to just hold on the minimum values smaller (more negatives) than the no emission level.

Consequently, the next step is to distinguish between two areas on the signal: (i) where the points are getting smaller (more negatives) until arrive to the minimum value; (ii) where the points start getting bigger (less negatives). If the idea is understood, then it is easy to decide that a good way to analyze the signal is making small length vectors (with eight points) and to calculate their minimum value; it permits to obtain a vector eight times shorter than the samples vector with all the minimum values of each small segment.

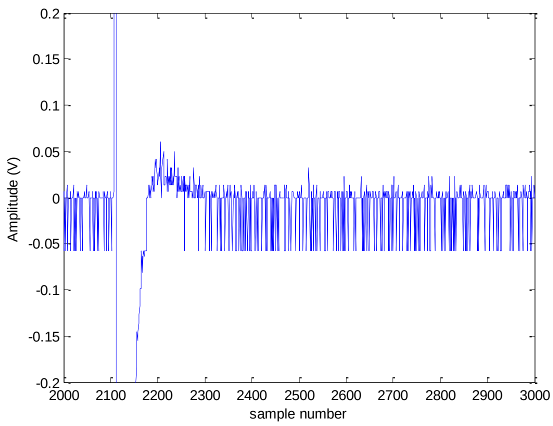

Figure A5.3 Non emission level up to -0.065 *V*

The size of the segments that divide the signal in smaller parts is a critical parameter of the code; it is not difficult to realize that the minimum size of the segments will provoke the maximum time running the code because this part of the code is the one that takes more time to carry out by the system (see Table A5.1). Then it is essential to find a medium terminus giving priority to the needs of the project.

Table A5.1 Time dependence on the execution's time and minimum time separation detected between two consecutive peaks due to the size of the segments using the same data file.

Segment's size (# of points)	*Time executing (s)*	*# of peaks detected*	*Min. Time separation (µs)*
4	67,8	395	12
8	30,5	382	28
16	17,3	363	60

Analyzing table A5.1 it is possible to see that the effect on execution time is huge; in consequence if not necessary then the best option is to use the medium size. And only when it will be essential use a smaller segment's size. With the bigger segment's size are lost some peaks that should appear in the histogram. Working with MatLab code it has been considered that using 8 points a great fraction of the peaks (96%) that must contribute to the code are identified.

If the whole group of identified peak obtained during the analysis it is not considered the values greater than -65 *mV* (samples due to electronics), then the relative minimums calculated is shown below.

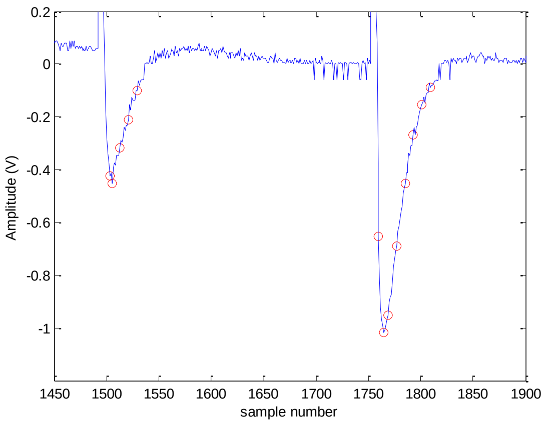

Figure A5.4 In red, relative minimums smaller than -65 mV

Where the red circle indicates the position of the relative minimums along the curve; a feature to observe is that the most part of them are on the right side of the peak. This is because the shape used by the amplifier is not symmetrical; accordingly the time from the signal to peak, is lower than the time from peak to signal (as was commented in Chapter 1, sub-section 1.1.3.).

Once it is done, the code has to distinguish between which points are absolute minimum (the minimums that the code uses to do the histogram) and which of them are just relative minimum of its segment. To do that the code will compare one value with its previous and following value. In consequence the code will

obtain an absolute minimum when these values are bigger (less negative) than the value that is analyzed.

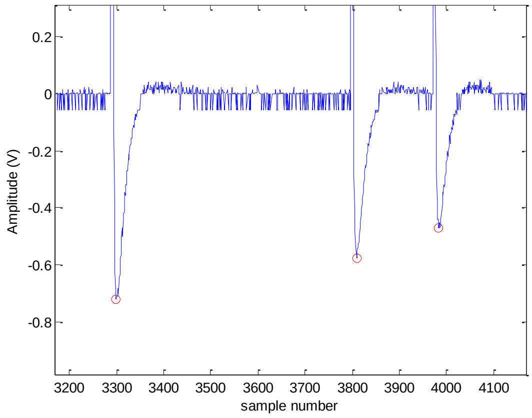

Figure A5.5 Absolute minimums detected by the code in red

The figure A5.5 shows how the code works for the minimums that will contribute to the histogram. It is essential to comment that here is possible to remove some peak that should be count when comparing two consecutives relative minimums exist the probability than both peaks are absolutes minimums, but the statistics of these events is so small that this error can be accepted.

A5.2.2. Overlap

One key parameter of the program is to give an idea of how the dead time of the system is; in other words, to know if the distance between the radioactive source and the sample to analyze is optimum.

On the one hand if the source is too close to the sample, then the detector will receive a number of photons too big to be able to have a good response; in consequence, the information of the photons will be overlapped; it means that the second photon arrived to the detector will contribute to the histogram with a wrong energy quantity.

On the other hand, if the distance from the source to the sample is too big, a fraction of the information could be lost, because the photons emitted by the source will not impact on the sample.
It is easy to understand that the worst option of both is to have the set up explained in the first case, where the source is too close to the sample. Then, for avoiding counting this photons in the histogram with their modified energy, the program incorporates an option that could be used when the user decide. In order to explain this idea easily, it is important to know how is the behaviour of the data when appears an emission peak.

In figure A5.5 it is possible to see that before every single minimum peak, the system has a series of positive values. This is the key for avoiding overlap effect.

The first step is to find one peak and create a variable with the 40 consecutive points from the peak minimum value. Then we impose the overlap condition, which is to search where is located the value of the ten percent of the peak amplitude value in the variable commented at the beginning of the paragraph. The idea is to indentify if this value is positive or negative: if the value is negative, probably does not exist overlap; if the value is positive instead, it is sure that exists overlap; consequently the program remove the peak overlapped and does not consider it for the energy histogram. This part of the code is shown below.

```
condition(1)=0.2*y(Ifinal(1));
vecmin2(1)=vecmin(1);
[Y(1)]=0;
yoverlap(1)=0;
for j=2:1:(npc-5)
   condition(j)=0.2*y(Ifinal(j));
   if condition(j)>threshold
      condition2(j)=threshold;
   else
      condition2(j)=condition(j);
   end
   for i=1:1:40
      nooverlap(i,1)=y(Ifinal(1)+i);
      nooverlap(i,j)=y(Ifinal(j)+i);
   end [Y(j)]=find(nooverlap(:,j)>=condition2(j),1);
   matchpos(j)=x(Ifinal(j)+Y(j));
   yoverlap(j)=y(Ifinal(j)+Y(j));
   if yoverlap(j-1)*vecmin(j)>=0
      vecmin2(j)=vecmin(j);
   else
      vecmin2(j)=0;
   end
end
noovernz=nnz(vecmin2);
[z]=find(vecmin2<0);
Ifinaltest=[1,noovernz];
for i=1:noovernz
   vecmin3(i)=vecmin2(z(i));
   Ireal(i)=Ireal(z(i));
end
```

It is worth to comment that avoiding overlap in the histogram the program takes more time running, consequently the user may decide when it is necessary (normally when the source is changed or the set up moved) or when is not important. In order to be able to choose easily which mode is going to be used a parameter is introduced on the code, and also a visual indicator on the LabView display.
In order to have an idea of this difference of time, a comparison has been done it and will be shown in Table A5.2.

Table A5.2 Time running comparison between a code with or without the overlap condition.

File length≈0.4 M points	*Overlapped peaks*	*No overlapped peaks*
Peaks number	1490	1253
Time running (s)	148.997	148.357

Considering the table above, I consider that it should be usual to use the condition of avoid overlap, because the histogram obtained will be clearer and the time difference it is not big enough.

A5.2.3. Histogram's bar width

The main objective of this project is to obtain a histogram of the different photon's energy, expressed trough the oscilloscope as voltage. In order to establish the bar's width it is necessary to see which are the upper and lower values that are going to be pictured. To do this long data files containing one and a half million points were taken, and it was possible to determine that the maximum amplitude (voltage) to represent will be 2 *V*; the lower limit was previously determined by the noise level on the signal; its value is -65 *mV*.

In order to choose the bar's width, it is going to be represented the same data sample, obtained in a measure with an external divisor probe, with different thicknesses (see Figures A5.6 and A5.7). Then it will be easier to choose the bar size to observe clearer the peak's histogram.

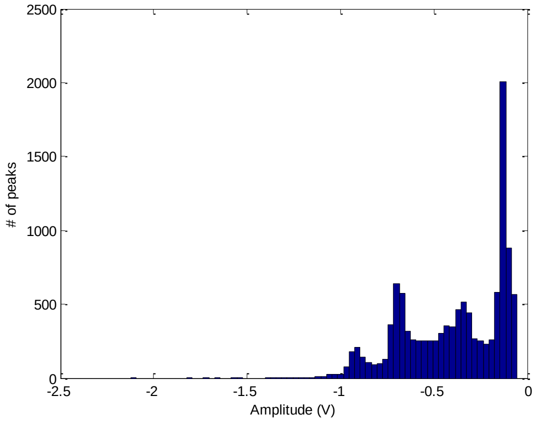

Figure A5.6 Amplitude histogram 0.03 *V* bar's width

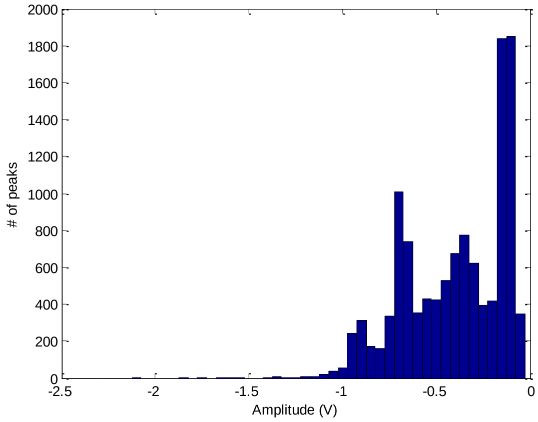

Figure A5.7 Amplitude histogram 0.05 *V* bar's width

Figure A5.6 shows clearer the results that we expected to obtain. And it is possible to check that increasing the bar's width the histogram shows worst the result. In conclusion, the best bar's width size for our set up is 0.03 *V*.

Annex VI

Dynamic Data Exchange in LabView (DDE)

In chapter 4 it is commented that could exist the possibility to obtain the data from LabView directly via DDE instead of how it is performed at the moment.

The objective of this annex is to show (Figure A6.1) how should be established a DDE connexion between the USB digital oscilloscope and the LabView.

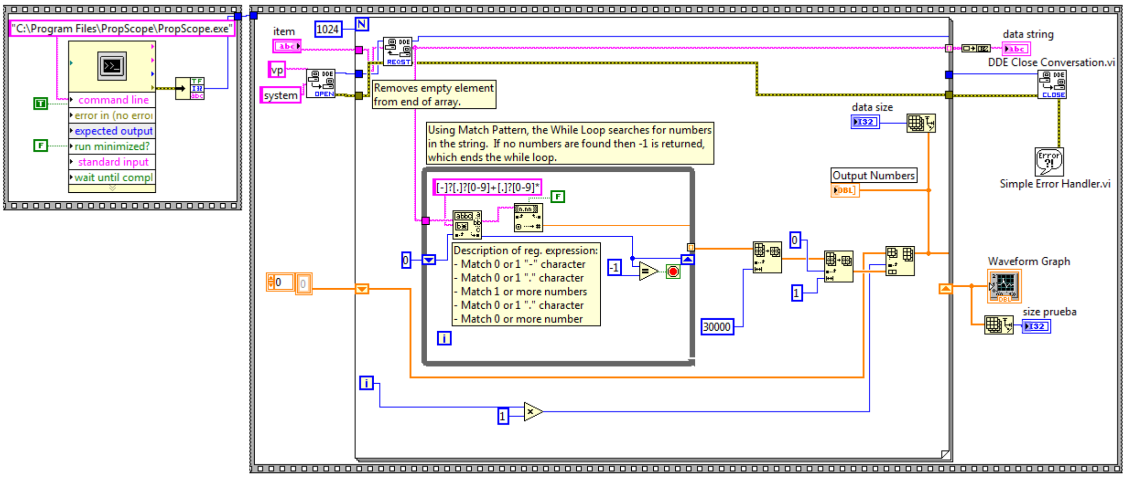

Figure A6.1 DDE connexion between PropScope and LabView